MODERN ROAD CONSTRUCTION

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A PRACTICAL TREATISE
FOR THE USE OF ENGINEERS, STUDENTS,
MEMBERS OF LOCAL AUTHORITIES, ETC.

BY

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PREFACE TO SECOND EDITION.

The original edition of this work has been so favourably received by road engineers at home and abroad, and the amount of new matter and information acquired as a result of the experiments and investigations that have been made in the interval has been of such interest, that, at the request of the publishers, the author has completely revised and remodelled the book to its present enlarged form.

The war has emphasised the immediate necessity for improved highways and thoroughfares, and for the provision of a substantial road structure which will be suited to the traffic. Motor transport has demonstrated itself an economic success, and it is shown in the text that, up to a radius of about forty miles, goods can be carried more effectively and as economically as by the railway as at present administered. A similar degree of satisfaction can be obtained in dealing with passenger traffic in certain circumstances.

Roads will, therefore, be subjected to a far greater amount of traffic than has been the case in the past. The increases shown in the traffic returns are an indication of the popularity of the motor vehicle, but, in the view of most people, they only give a slight idea of the future increase of such traffic.

It is explained that the provision of good and suitable roads will reduce the running costs of this form of traffic by about 20 per cent.; and, in consequence, it is desirable that every effort should be made to instal such a form of structure that will give this or even better results.

The greatest care has been taken to give information which will be generally useful The author has made very free comments for and against the different classes of structures, and suggestions which, in his opinion, seem to overcome the difficulties that have arisen.

The bituminous pavement is very closely examined, because this class of structure seems to have greater possibilities for success from every point of view; the information is in such detail on this subject that there should be little difficulty in carrying out the work by direct employment of labour.

Road engineering is a science requiring careful study and investigation, and the author hopes that in this work attention is so drawn to the various factors that a closer examination will be made and records kept with the object of improving the practice, and he will be pleased to receive from the reader any suggestions which will make the work of more value.

FRANCIS WOOD.

BLACKPOOL, *December* 1919.

PREFACE TO FIRST EDITION.

THE author has endeavoured to bring together in this volume a series of notes that have been accumulating over a period of years. Among them are certain theories which may possibly not be regarded as orthodox. Where this may be the case, careful and studied reasons or data are given for the variation.

The followers of Macadam, Tresaguet, and Telford may also consider that the principles which have been accepted for a generation are in some degree treated perfunctorily, but the real position is that the principles with which their names are associated are taken as general lines for thought. Since their time, experience and knowledge have shown how these can be developed and brought to a stage of greater refinement and usefulness.

It is only by systematic and detailed inquiry into obscure points of construction and of disintegration that an advance can be made, but behind that scientific inquiry, and guiding it, must be the sympathetically inclined, practical, and experienced road engineer.

Too much reliance must not be placed on scientific research or laboratory experiments. The laboratory work will assist in giving the engineer knowledge of what to avoid, but it will not necessarily give him the material to use.

Probably there is no form of construction that is subject to such varying conditions as the structure forming the surface of a road. It would not be too extreme to say that this country provides the severest conditions of any in the world. One of the most trying and unknown factors, to which little regard is usually given, is the moisture in the

atmosphere. Those successes which are said to be so prevalent in the drier atmosphere of other countries would probably, in some cases, have failed under our moist conditions. The other factors are almost too well known to be mentioned—heavy rains, drizzling showers, summer heat and winter frosts, variations of horse and motor traffic, iron- and rubber-tired wheels, intermittent or continuous traffic, grade and contour: then the road may be broad and open, or sheltered and shaded by trees; it may be low-lying and consequently badly drained, and so on. Each have their effects, and they cannot be anticipated; all that can be done is to study the combinations.

It will, for this reason, be unwise to draw the conclusion that because a form of road construction has been very successful in one particular place or district, it will, without amendment or alteration, prove equally successful in another totally different district and under dissimilar conditions. Obversely, it need not be the case that because a form of construction has failed in one place, it will fail elsewhere.

A critical examination is made of materials used, but it must not be taken that they should be eliminated from use where the criticisms are adverse It is for the road engineer to determine the places where they can be used with success. The criticisms are the personal opinions of the author, and their justification is amply set forth.

An inquiry is made into the question of the traction wear on macadam roads: whether, by itself, it has any greater wearing capacity than it has on wood-paved or asphaltic road surfaces.

Abrasion or attrition tests of stone have been useful so far as the waterbound roads are concerned, but in the more modern methods of construction it is shown that the stone will not be given the opportunity to abrade; it will be held in position permanently in the same manner that the aggregate in concrete is held in position by the cement that is used as a binding agent. The great difference is that in this case the cement is hard and non-resilient, while in the other the binding agent is ductile and gives a resilient mass. Thus stone will have a different value, and in all probability a stone now regarded as soft will have almost an equal wearing capacity in such a pavement to a hard stone, if not a greater.

The example of soft wood is an illustration. It wears more satisfactorily than hard wood, because its fibres are more resilient and not too quickly affected by traffic and weather conditions.

The tars and the natural bitumens as binding agents are fully considered, the stable and known characteristics of the latter showing to advantage as against the cheapness and unknown qualities of the former.

In making comparisons of roads, the best method is to take a careful census of the traffic. An example which has been adopted by the Road Board is given in the text.

The census would be misleading if in one case it was taken over twelve hours and in another over twenty-four hours, as there may in one case be a day and night traffic, and in the other only a day traffic. The traffic should be taken hourly, as it will probably be found that traffic spread over equal periods of the day will wear less rapidly than in the case of the same traffic confined to very few hours.

The width of a road as a guide to the traffic rate is also misleading. A straight road with the traffic confining itself to the centre of the road is affected much more rapidly than a similar road where the same traffic spreads itself over the whole width. It is, therefore, advisable to remark on this in the census return, or adopt a standard width for each line of traffic.

The author is indebted to Mr Clifford Richardson for his kind permission to use the analyses and figures in connection with the various bitumens mentioned in the chapter dealing with the subject. They are given in even more detail in his work on *Modern Asphalic Pavements.*

Much of the matter has already been given in a series of lectures and in articles in the technical journals.

It is, however, due to the apparently wide interest that is taken in improved methods of road construction, as evidenced by the correspondence from engineers, members of local authorities, and others, both at home and abroad, that the author has attempted to give in a concise and not too highly technical form the leading characteristics and details of modern roads without overlapping in any serious degree the works of other writers on the same subject.

FRANCIS WOOD.

LONDON, *June* 1912.

CONTENTS.

CHAPTER I.

INTRODUCTORY.

CHAPTER II.

MACADAM ROADS.

CHAPTER III.

WEAR OF ROADS.

CHAPTER IV.

EFFECT OF TRAFFIC ON ROADS.

CHAPTER V.

FOUNDATIONS.

CHAPTER VI.

TAR.

CHAPTER VII.

BITUMEN.

CHAPTER VIII.

METHODS OF USING TAR AND BITUMEN.

PAGE

CHAPTER IX.

METHODS OF USING TAR AND BITUMEN (*continued*).

CHAPTER X.

ROLLERS AND ROLLING.

CHAPTER XI.

PAVING.

CHAPTER XII.

COST OF MAINTENANCE OF ROADS.

MODERN ROAD CONSTRUCTION.

CHAPTER I.

INTRODUCTORY.

The attention of road engineers has in recent years been especially called to the ever-increasing traffic, principally self-propelled, because of the damage that has developed on the roads and which is coincident with the entrance of the motor vehicle into the public service. Macadam roads have satisfied the requirements of the public for a great many years, but under the new conditions they seem to fail in a remarkably short space of time. A careful examination into the whole of the factors which have their effect on the road structure will demonstrate why the deterioration is so rapid and how it can be remedied, but owing to the great mileage of roads made with macadam, it is a matter of serious consideration as to how the cost of any remodelling of the structure to suit the new conditions can be met.

Main Road Maintenance Costs.—In order to properly appreciate the position of the road authorities in England and Wales, we may take the statistics that are issued by the Road Board in their Annual Report, extracting from them the figures which apply to the main roads only.

TABLE I.

	Mileage.	Mainten- ance.	Improve- ments.	Other Items.	Loan Charges.	Average Cost per Mile Mainten- ance.
		£	£	£	£	£
Urban main roads .	4,366	1,089,449	98,592	..	173,581	250
Rural main roads .	23,833	2,897,361	21,002	..	59,854	122
County borough roads	10,304	1,544,938	116,536	881,520	1,735,068	150
London authorities .	2,216	871,664	{86,623 / 88,025}	666,648	1,077,378	393

Here it is shown that the cost of maintaining the urban main roads is equivalent to 5d. per superficial yard and the rural main roads 2½d. per superficial yard.

Reconstruction Costs.—The cost of a road surface which will satisfactorily withstand moderate or heavy motor traffic prior to 1914 was about 5s. per superficial yard. It would thus take twelve years for the average urban authority to convert these roads to a satisfactory state, expending each year the whole of the maintenance costs (assuming they are all of a macadam type), and twenty-five years for the rural authority to treat the roads in the same manner. If the roads were reconstructed at once, it would take the same period to repay the loan (without taking into consideration the extra time that would be involved, and which would represent the interest on the borrowed money), leaving nothing for the maintenance of the new form of construction that may be necessary during the period of the loan

But there is another point which is of importance: the Government does not sanction loans for such purposes for a period beyond ten years, therefore, so far as the rural districts which have 23,833 miles of roads under their control are concerned, the cost of such a form of road construction would be equivalent to two and a half times the maintenance cost during the ten years, exclusive of loan charges and new maintenance. This is not perhaps at first sight a great difference, but when the amount raised from the rural areas is £2,897,361, and it is to be increased by about £6,000,000, it becomes a very serious problem; similarly with the urban areas, the amount to be obtained is a considerable sum from their limited areas.

The war has intervened and raised the cost of both labour and materials more than double, and it is probable that these costs will not return to anything like the figures that prevailed before and during 1914. Hence the difficulties of the road authorities, who are faced with the problem of improving their road structure, are intensified.

Taxation Proposals.—There have been many proposals to overcome the financial side of this problem: one of them that has received considerable support is to continue the petrol tax which was placed on petrol-driven vehicles in 1909, and which has since been greatly increased, and to place in addition a tax on motor buses at the rate of ⅜d. per car mile.

This proposal has been amplified on the following lines, the cost per bus per annum being calculated on a 100-mile basis:—

	Per Bus Mile.	Per Bus. Per annum.		
	d.	£	s.	d.
For a specially constructed wood-paved or asphalted road on reinforced concrete	$\frac{3}{8}$	57	0	0
For a wood-paved road (on concrete)	$\frac{7}{16}$	66	10	0
For an asphalt road (on concrete)	$\frac{7}{16}$	66	10	0
For a granite sett or durax-paved road (on concrete)	$\frac{7}{16}$	66	10	0
For an asphaltic macadam road	$\frac{1}{2}$	76	0	0
For a tarred slag macadam road	$\frac{3}{4}$	114	0	0
For a tarred limestone macadam road	$\frac{3}{4}$	114	0	0
For a tarred granite macadam road	$\frac{3}{4}$	114	0	0
For a granite water-bound road	1	152	0	0
For a limestone water-bound road	1	152	0	0
Other water-bound roads	1	152	0	0
For a road partly wood-paved and partly macadamised, with water-bound metalling	$\frac{11}{16}$	104	0	
For a road partly wood-paved or granite, paved and partly macadamised, with water-bound metalling	$\frac{11}{16}$	104	0	0
For a road partly paved with wood and partly macadamised with tarred macadam	$\frac{9}{16}$	86	0	0
For a road partly paved with setts or durax and partly macadamised with tarred macadam	$\frac{9}{16}$	86	0	0
For a road partly wood-paved and partly paved with setts or durax	$\frac{7}{16}$	66	10	0
For a road partly paved with wood and partly with asphaltic macadam	$\frac{1}{2}$	76	0	0
For a road partly paved with granite setts or durax or partly with asphaltic macadam or lithofalt		76	0	0

The writer is not aware whether such a proposal as this has been adopted, and in the case of a bus which is plying for trade in a district where such a charge is made, it probably will not materially affect the company running the buses, because the inhabitants of the district have to pay these charges; if they do not patronise them under these conditions, then the bus company would not run the vehicles.

A motor-bus chassis is not materially different from a great proportion of the commercial vehicles which are so prevalent. The three-

ton vehicles used by the Government Departments in the prosecution of the war are particularly after this type, so that whatever charges may be made on motor buses should equally apply to these other vehicles, as they will obviously be capable of causing the same proportional damage.

In London there is a large proportion of bus traffic as compared with other traffic, and the writer had a census taken of the traffic passing through Fulham.

TABLE II.

Position.	No. of Vehicles, 1914, per week.	No of Vehicles, 1909	Motor Buses, 1914	Motor Buses, 1909	Horsed Buses, 1909.	Proportion of Motor Bus to General Traffic.	Total No. of Motor Buses per annum.	Amount per Car Mile at ⅛d.	Total Cost of Repair and Repavement of Road per Mile	Average Rate of Wear, 3 Years, 1906–1909	Rate of Wear, 1914	Per cent. Increase+ Decrease−.	Per cent. Increase in Traffic in 5 Years
								£	£				
Fulham Road, Broadway	42,817	25,044	12,216	4276	5564	0 29	682,000	980	598	0 18	0·11	−15	69
" " Fulham Park Road	25,614	14,788	7,816	1692	5770	0 28	381,000	595		0 096	0 8	−10	78
Putney Bridge .	56,873	28,502	14,288	8082	7874	0 25	742,000	1160	.	..	.	..	130
Harwood Road . .	25,760	12,584	6,334	2312	4096	0 24	880,000	518	454	0·003	0·08	−14	105
Fulham Palace Road .	33,610	17,200	6,688	4502	802	0 20	347,000	542	300	0·043	0·04	−7	95
New King's Road .	29,849	7,704	1,783	56	2	0·06	93,000	140	437	0·078	0 07	−4	300
Dawes Road . . .	23,804	11,058	4,914	2700	16	0·21	255,000	400	426	0 09	0 07	−22	110
Lillie Road . . .	35,444	21,438	5,040	102	3558	0 14	262,000	410	470	0·186	0·17	−8	65
Wandsworth Bridge Road	15,006	9,962	880	56	1244	0 05	43,000	67	445	0 03	0 09	−3	51
North End Road .	19,628	11,268	1,001	128	2954	0 09	97,000	162	511	0 119	0 12	+2	73

Proportion of Bus Traffic.—Table II shows that although the motor-bus traffic is only on an average ·22 of the number of vehicles using the roads, the income would be, on the ⅛d. per car mile basis, £424 per mile as against a total cost of £464. The numbers of motor lorries, light tractors, and traction engines are increasingly using these roads at a rate varying from 141 per cent. to 590 per cent., and the increase in the total number of all classes of vehicles is varying from 51 per cent. to 300 per cent. Yet with all this increase of traffic, the rate of wear of the pavement, which is in every case soft wood, gives a clear indication that the wear is at a less rate compared with the three years prior to 1909, when there was mainly horsed traffic using the streets. There are three cases where the income would be much less than the actual cost of repairs, but it will be noticed in these cases that the percentage of motor buses to the general traffic is small; where, however, it approximates to 20 per cent. of the general traffic, it is about as much as the total cost of repairs.

Wear Decreasing.—It is therefore permissible to suggest that where a road is formed of material which is suited to the traffic, the wear is

not as great as was the case under horsed traffic, the pounding of the horses' iron shoes doubtless being a considerable factor; or it may be that the extensive use of rubber tires contributes largely to the reduction, the rubber wearing rather than the surfacing material of the road.

This is a confirmation of a conclusion which was arrived at by a committee appointed by the Chamber of Deputies in France as far back as 1831: "Steam vehicles weighing 4 tons fully loaded and running at an average speed of 10 miles per hour, with larger wheels than other vehicles, do not destroy the road surface like the hoofs of animals, and cause less injury to the road than horse-drawn vehicles"

Traffic Increasing.—A further examination of the figures will be instructive. It would be natural to expect that the number of motor buses that have substituted horsed buses would have been fewer in number, had they only taken the same traffic as the horsed buses; but it will be seen that they have greatly exceeded the number of horsed buses, and it must be therefore anticipated that other classes of traffic will similarly increase with their increasing popularity. It is evident from the figures given that this is actually the case. The number of commercial motor vehicles is far in excess of the vehicles that were used in 1909 (Table IIA.).

TABLE IIA.

	Number of Motor Lorries, Tractors, and Traction Engines.	Number of Motor Lorries, Tractors, and Traction Engines.	Increase in Five Years.
	1914.	1909.	per cent.
Fulham Road, Broadway	858	168	410
" " Fulham Park Road	371	132	250
Putney Bridge	1061	306	246
Harwood Road	662	96	590
Fulham Palace Road	985	144	584
New King's Road	776	210	270
Dawes Road	441	108	309
Lillie Road	536	222	141
Wandsworth Bridge Road	285	102	180
North End Road	219	54	305

Cost of Maintenance per Vehicle.—The total cost divided by the number of vehicles is equal to $\frac{1}{10}$d per vehicle mile. This therefore represents the cost of the wear of the road by vehicular traffic.

Cost of Maintenance per Ton Mile.—If, however, we take weight as a factor instead of the vehicle, then it works out at $\frac{1}{33}$d. per ton mile.

Suppose a motor car weighing 1 ton travels 10,000 miles per annum, then the cost of the damage or wear to a suitable form of road structure would be $\frac{10,000 \times 1}{33}$ = £1, 5s. 3d. per annum. If a motor bus weighing 6 tons travels 30,000 miles per annum, the damage is represented by £22, 17s. If a motor lorry weighing 4 tons and a load of 6 tons averaging $7\frac{1}{2}$ tons travels 40 miles per day, *i.e* 90,000 ton miles, the cost is £12, 4s per annum.

Basis of Cost of Maintenance.—This is based on a pavement costing 8s. to renew every fifteen years, and a repairing bill of 3d. per superficial yard per annum, bringing the total cost to 9·4d. per yard per annum

But the cost of maintenance is not in true proportion. For example, in other roads there may be only one quarter of the traffic, and as the pavement may last four times the length of time, it would not be possible to assume that a pavement would last sixty years; the limit of its life should be twenty years The cost of repair may be reduced to about $1\frac{1}{2}$d. per superficial yard. Basing the figures on pre-war standards, the bituminous pavement costing 5s per superficial yard represents 3d. per superficial yard per annum, added to $1\frac{1}{2}$d per superficial yard for repairs: the cost is $4\frac{1}{2}$d. per superficial yard per annum. Instead of the width being 30 feet, assume it to be 7 yards; then the cost of maintenance would be £231 per mile. One quarter of the traffic per foot would cost =·08 per ton mile. Thus a motor car of 1 ton, travelling 10,000 miles per annum, would cost £3, 6s. 8d., the motor bus on the basis mentioned above would cost £60, and the motor lorry £30.

Assuming, therefore, that every vehicle was taxed at the rate of 0·08d. per ton mile, the revenue that would be received would be sufficient to pay for the maintenance of the roads that were traversed on the above basis, provided that the roads were built with a suitable structure at pre-war rates.

For a comparison of actual maintenance costs see page 70.

Decreased Running Expenses on Good Surfaces.—It will be gathered later that with an improved surface the saving in cost of the running of petrol-motor vehicles would be so considerable that, if a tax is to be levied, a far greater tax could be imposed than was the case in 1914, without increasing the owner's total running cost. There seems no justification for limiting the tax to the petrol vehicles, as the other types of vehicles wear the road to an equal extent with the same weight. It is also shown that the steel-tired vehicles do much more damage to the road surface than rubber-tired vehicles, and these vehicles might there-

fore be more severely taxed than rubber-tired vehicles. There can be little doubt that if a tax is to be placed on vehicles, it should be on all vehicles, and proportioned to the load and mileage travelled.

The complaints of motor buses doing the damage to the roads arises from the fact that these buses travel with regularity on a certain fixed route, and the frequency of the service causes the damage to be apparent at an earlier date than would have been the case if their route had been constantly varying over many different roads. Wherever these or other vehicles of a similar or of a lighter or heavier class run over a macadam road with similar frequency, the same results would appear. It is interesting to learn the number of heavy vehicles. In 1913-14 the census taken indicates that the number of heavy motors was 18,005. Of this number the estimated number of motor buses was 5000, but 3000 were confined to the streets of London, and a proportion of the remaining 2000 were probably confined to the paved streets of the provincial towns. It is, therefore, a number under or about 2000 motor buses that have done the damage that is complained of. But there are 13,000 other vehicles which are probably of a heavier type than the motor bus. These are also to some extent confined to the large towns; but assuming that half of them travel on the roads outside the London area, they then number three and a half times the motor buses, and must have done equal damage to the roads; but that damage has been spread over a much wider area, and is not so soon apparent, but the damage will appear later on. The War Department is, according to the Press, in possession of anything between 50,000 and 100,000 motor vehicles; these are to be released, and will doubtless be used for commercial purposes. The greater proportion of the vehicles used by the War Department were built on similar lines to the motor-bus chassis, and if only 50 per cent. of the smaller of the estimated number of vehicles are released and put on the roads, there will be twelve and a half times the number of motor buses, or four times the number of the heavy motors other than buses running on the roads, and the damage that will be made apparent on any road that is not provided with a suitable structure may be easily imagined.

Traffic Damage to Roads.—So severe has been the effect of this traffic on the unsuitable road surfaces existing, that it has been suggested that there should be a demand made on the railways to give better facilities and cheaper freights, in order that the roads need not be subjected to the heavy traffic, which self-propelled vehicles are able to deal with more economically by road, and thereby entice this traffic from the railways. The war has, however, strengthened the hold of motor vehicles on the business public; the Government has made a huge demand for vehicles of the commercial type, and their value for war purposes

has proved inestimable. So that from all sides there is a definite opinion that motor traffic after the war will be very great, and the roads will be subjected to a much severer intensity than has ever been the case in the past.

Railways and Traffic.—Whether railway companies will alter their methods and revolutionise the system of dealing with goods traffic is a question that affects the road problem, and it will not be out of place to examine in some more or less general manner whether it is actually the case that motor vehicles seriously compete with railways.

Necessity for Economy.—It is obvious the war has so drained the finances of the country that it is absolutely necessary in the interests of the public that economies be effected in every possible direction. If motor vehicular traffic is not economical, the trader will be the first to recognise the fact and adopt the cheapest form of conveyance for his goods to his customers.

Advantages to Motor-Vehicle Owner.—Where a trader employs his own motor vehicle, there are a number of advantages that are at once apparent, to which it will be difficult to give or even estimate a cash value. They are (1) the certainty of delivering within a known time, (2) reduction in the number of times the goods are handled, (3) less damage to goods, and (4) the goods are under the direct control of the trader until they are placed with the consumer. These are distinct advantages which cannot be overrated, and are potent factors which are difficult to counterbalance except by clear advantages in the freight charges. Railway companies will no doubt be able to make economies in freight charges, but it will involve drastic alterations, and these alterations are probably extremely difficult to carry out on a comprehensive scale, especially in systems which are old and established. Co-operation on all sides would be necessary. Structural alterations require large capital expenditure, and if previous capital expenditure has not been wiped off by means of depreciation, the effect is to increase the cost unless the economies are on a commensurate scale.

Companies may come into agreement as to a policy; they equally can come to an agreement as to the charges, and these may be made unfavourable to goods carried, especially if there is no other means of counteracting it—for example, by competition ; the competition is to be found in transport by road.

Railway Costs.—In order to study the charges made for the collection and delivery of merchandise and minerals, the Board of Trade returns of railway administration are available for 1913. From these returns the following particulars are extracted, and from them the deductions have been made :—

The total authorised capital is	£1,400,000,000
" expenditure per annum	81,224,000
" mileage travelled	412,520,000
" income from goods of all kinds .	66,640,000

of which £33,000,000 is for the carriage of merchandise (less expenses for collection and delivery to and from the railway).

Receipts per Ton.—The average receipts per ton were as follows:—from merchandise, 9s. 0·6d.; from minerals, 2s. 1·7d.

The mileage travelled by goods trains was—

Loaded	140,449,000 tons
Empty	21,235,000 "
Shunting, etc.	119,142,000 "

Thus the mileage for shunting and empties is just about equal to the loaded-train mileage.

Tonnage of Goods carried.—If the tonnage of goods carried is taken as the amount originating on any one system, it equals 372,037,000 tons, or a trifle over 2·3 tons per train mile; and as the receipts are 98·86d. for goods, it is evident that 3s. 7d. is the value of the receipts per ton.

But the receipts from merchandise =108·6d., and the receipts from minerals are 25·7d. per ton, *i.e.* in the ratio of 4·22 : 1. The tonnage is 73 millions of merchandise and 299 million tons of minerals; the ratio is 1 : 4·1.

Average Train Mileage.—Assuming that the freight charged for minerals is 0·5d. per ton mile, then the average freight of merchandise would have been 2·11d. per ton mile, and these figures divided into the receipts give the average mileage per train of 51·40 for minerals and 51·47 miles for merchandise, or an average of 51·4 miles for all goods train journeys.

Having obtained the average journey, the load being 372,037,000 tons, the ton mileage is 19,123,000,000; this divided by the train mileage =135 tons per train.

Thus if the average train is made up of thirty-four trucks, there is an average of 4 tons per truck.

Approximate Cost of Collection and Delivery.—The cost of collection and delivery at each end varies considerably, but an average of 3s. per ton seems to be fair, and if 1 mile is added at each end, the total distance is 53·4 miles and becomes equal to 1·35d. per ton mile, or a total of 3·46d. per ton mile.

Approximate Cost of Motor Vehicles.—A motor vehicle costing at pre-war rates £600 and carrying 4 tons on good and suitable roads would not run to more than 8d. per car mile out and home, or 1s. 4d. per car

mile for the loaded journey, *i.e.* 4d. per ton mile. The heavier the load the less costly will be the journey, and it is therefore seen that as the trader would build his vehicle to suit the goods he has to carry, it may easily follow that as the motor vehicle costs no more to carry 4 tons of material of considerable density or 4 tons of light density, the advantage is more likely to be in favour of road transport.

Railway Rates for Goods.—From a railway rates book it will be found that goods are divided into classes, and, without going too closely into the matter, the rates for goods to two towns are taken :—

	108 Miles.	31 Miles.
Class B . .	·06d. per ton mile	2·0d. per ton mile
,, C . .	1·00d ,, ,,	3·0d. ,, ,,
,, 1 . .	1·75d. ,, ,,	3·4d. ,, ,,
,, 2 . .	2·00d. ,, ,,	4·0d. ,, ,,
,, 3 . .	2·70d. ,, ,,	4·6d. ,, ,,
,, 4 . .	3·00d. ,, ,,	6·0d. ,, ,,
,, 5 . .	3·50d. ,, ,,	7·0d. ,, ,,

Class B and C covers various classes of minerals.
,, 1 covers damp-proof felting, office furniture, belting, etc.
,, 2 ,, newspapers, confectionery, etc.
,, 3 ,, hardware, bicycles, fenders, machines, etc.
,, 4 ,, clothing, enamelled ware, leather, etc.
,, 5 ,, mouldings, bedding, beds, etc. etc.

Comparison Motor v. Railway Transport.—Add to these charges the collection and delivery charge of ·66d. per ton to those governed by the distance of 108 miles and 2·32d. to those governed by the distance 31 miles, we have all classes of goods carried more cheaply by rail for a distance of 100 miles, but where the distance is within the ordinary range of a motor vehicle it is even cheaper to carry all classes of goods by road transport. When the case of a heavy motor and trailer is considered which carries 10 tons, the running costs would not be more than 2s. per loaded vehicle mile or 2·4d. per ton mile, which is still more favourable.

There is another aspect of the case: the averages for goods are given as 4 tons per truck and the distance carried is 51·4 miles, but the tonnage of merchandise is in the ratio of 4·1 to 1 of minerals, the mileage being the same; the tonnage of merchandise should therefore be 26·4 to 108·6 of minerals, or 10 trains of 135 tons each of merchandise to 41 trains of minerals. It has been stated that the tonnage of merchandise is below 4 tons and more nearly works out at an average of 2½ tons, and that the mineral trucks are loaded to the average of 9 tons. The journeys for

merchandise must therefore be much longer and approximate more nearly to 80 miles, while the journey of the mineral train must be shorter and approximate to 22 miles. This means that instead of 10 trains of merchandise to 41 of minerals, the ratio is 15·4 trains of merchandise to 16·6 of minerals, or a reduction of 37 per cent in the total number of trains.

This brings the average of the cost from door to door to 3·01d. per ton mile. But this does not alter the contention that has been put forward, that for distances within the radius of the motor vehicle the cost of carriage from door to door is in favour of road transport.

Railway Methods Unsatisfactory.—It has been put forward that railway methods are antiquated, and that under a different system not only would goods be more expeditiously delivered, but a greater amount of material could be dealt with and greater efficiency secured generally. There is little doubt that alterations are being gradually made, but undoubtedly there is room for considerable improvement. The writer has had to wait three days for goods to come from the north of London to the south of London, and three weeks from Lancashire to the outskirts of London. There must be some defect in such a system, and it must be possible to arrange a method whereby goods could be delivered the following day after acceptance, just as passengers can be and are carried. While such delays continue to exist they are a distinct encouragement to traders to invest in commercial motors, and in consequence an improved form of road surface which will withstand such traffic in a satisfactory manner is absolutely necessary. The full advantages and benefits of an even and satisfactory road surface will only be reaped when it is in first-class condition.

Other Views of Railway Methods.— Other investigators of railway working have given a much worse view than is represented by the above. It is even represented that 97½ per cent. of the trucks on railways are lying idle during the year, and this is attributed to the waste of time involved by the methods that are in vogue for shunting, etc Clearing houses are suggested, and automatic transfer of goods from truck to truck; but so far as the writer has examined the proposals they are not too clearly demonstrated. At the same time it must be admitted that there are advantages to be gained by an automatic transfer of goods; especially as it is indicated in the Board of Trade returns that the mileage of shunting, etc., is within 80 per cent. of the loaded journeys, and it is therefore probable that the loss of time in delivering goods occurs in those places where shunting has to be carried out.

Regulations as to Use of Roads.—The road is public property, being designed, built, and maintained in the interests of the public, and yet

the designer of the road rarely, if ever, consults or is consulted by the user, who has a free hand and, at the present time, may place on the road any class of horse-drawn vehicle he pleases With regard to motor vehicles, he has to conform to certain regulations, particulars of which are given later, which define and limit the loads they are permitted to carry, the width of the tires, etc.

These regulations may be very desirable, but if they are not enforced, and the vehicle only tested before it is placed on the road, or at a time when it is not bearing its usual load, they are not as valuable as they might be.

There is no doubt that there must be limits which should be strictly adhered to.

Conference of Designer and User.—With reference to the question of the designer and the user conferring, although it is true that they rarely have the opportunity for so doing, there is obviously no reason why opportunities should not be made.

The *International Road Congress* is the only institution that has seriously attempted to bring the two together, and it is probable that this congress will in time be the means of giving to the legislatures of the various countries a just guide to the conditions applicable both to the designer and to the user of the road.

Comparison with other Track Methods.—If we examine into other classes of roads, we shall find, for example, that the designer of a railway would not lay down the lines of his track without ascertaining the limits of the locomotives that are intended to be used upon it.

Grades of Roads.—In modern schemes of railway construction the steepest grade, that should under no circumstances be exceeded, is settled after a most careful investigation has been made by the locomotive and engineering departments, and is very rarely greater than 1 in 150. It is usual to select a grade that can be used as far as possible throughout the system, either upwards or downwards, with level or comparatively level stretches in between. However, in road construction there is no limit to the inclination of the road, and grades of 1 in 5, 1 in 6, 1 in 8 are quite frequent.

India.—In certain parts of India, notably the north-west frontier, the military authorities design their roads and construct them so that the grade is limited to 4½ feet on 100 feet or 1 in 22 ; here the designer and user are in contact, and hence the roads are built to meet the special requirements. This grade is not excessive, and is one that might well be adopted as far as possible as a limit in this and other countries.

Power to draw Loads on Grades.—Such a reduction would greatly benefit the users, as will be seen from an examination of the accompanying

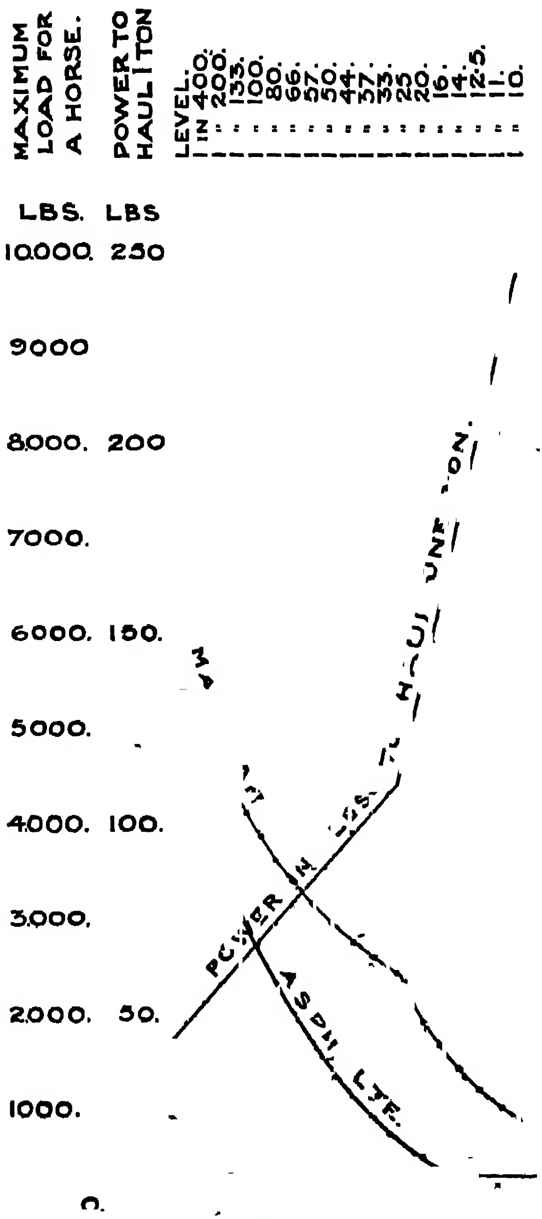

MAXIMUM LOAD FOR A HORSE.
POWER TO HAUL I TON
LEVEL.
I IN 400. 200. 133. 100. 80. 66. 57. 50. 44. 37. 33. 25. 20. 16. 14. 12.5. 11. 10.
LBS. LBS
10.000. 250
9000
8.000. 200
7000.
6000. 150.
5000.
4.000. 100.
3.000.
2.000. 50.
1000.
0.

FIG. 1.

diagrams (figs. 1 and 2), which show graphically how, in one case, the power required to be exercised by a horse to draw a load of 1 ton

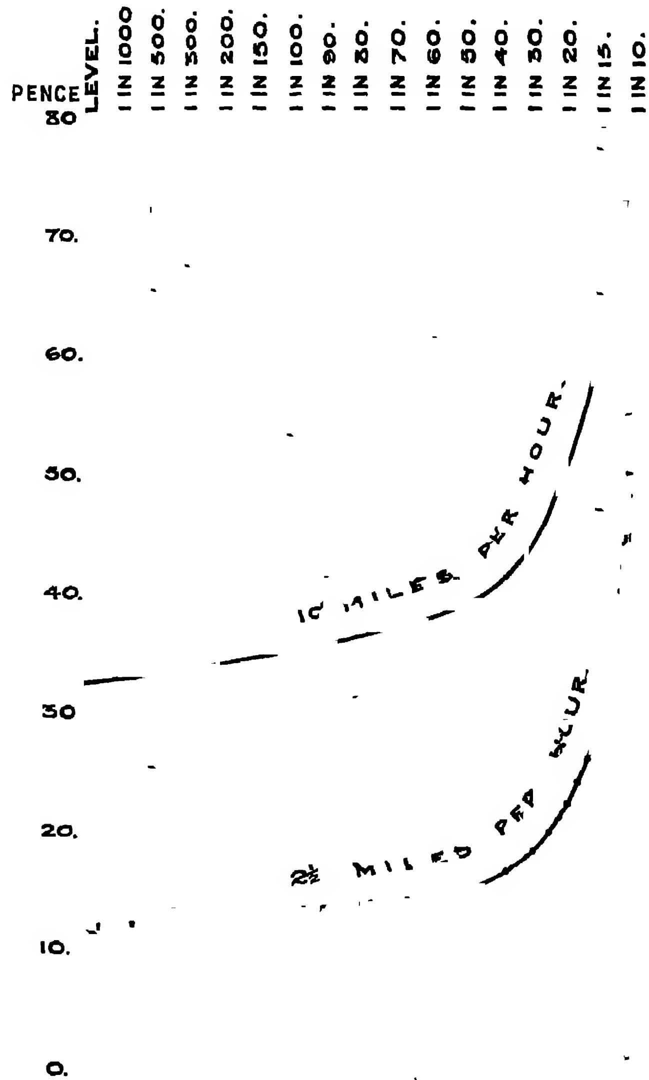


FIG. 2.—Top curve represents cost of 4-horse stage-coach drawing 1 ton over 1 mile at 10 miles per hour. Bottom curve represents cost of 4-horse waggon drawing 1 ton over 1 mile at 2½ miles per hour.

gradually increases as the grade increases from the level up to 1 in 20 in a fairly constant ratio, but after this limit the power required

increases very rapidly and in a much higher proportion. In the other illustration (fig. 2) there is a graphic representation of the cost of traction of vehicles at the rate of 10 miles per hour and 2½ miles per hour; the cost increases gradually up to a grade increase of 1 in 50, but after 1 in 20 the increase is abnormally in a high proportion.

Limiting Grade.—It is clear from an examination of both diagrams that the grade of 1 in 22, mentioned in a previous paragraph, should be the limit, and that any increase should be adopted only when the circumstances absolutely prevent the more favourable grade. The strain is as severe on mechanically propelled vehicles as it is on horse-drawn vehicles.

Effect of Surface Material.—The diagram (fig. 1) also indicates the effect of the material which forms the surface of the road: a macadam surface gradually decreases the effective power of the horse from the level to the grade of 1 in 20, after which the decrease is much more rapid; while in the case of asphalt, or surface similar to that of asphalt, the decrease is in a greater but a more constantly decreasing ratio.

Limit Grade for Asphalt.—If the effective power of the horse at a grade of 1 in 20 is taken as the limit, this power is seen to be exerted on asphalt when the grade is 1 in 60. Whether it is that horses are becoming more accustomed to the asphalt surface or whether it is that they are not so heavily taxed as to the loads they have to draw, on account of the advent of motor vehicles, it is the case that there are many examples of a grade of 1 in 40, and 1 in 27 is not regarded as unusual.

International Road Congress on Grades and Curves.—The International Road Congress held in London in 1913 thoroughly discussed the question of grade, and came to no definite conclusion as to the limit, because roads in hilly or mountainous districts would be extraordinarily expensive if even a grade of 6 per cent. was the limit; hence their conclusion: "Gradients on new roads should be as easy as possible having regard to the physical character of the country through which they pass, and they should be easier where there are curves, trams, or a preponderance of heavy traffic."

The curves on roads were another important part of road construction dealt with, and it was resolved that "although it is difficult to carry out the form of the contour of a road in many instances in conformity with the centrifugal forces, so that the outside of the curve should be super-elevated, it is desirable that whatever super-elevation can be given to a road at the curve, it should be done even if the whole contour of

the road is altered." When the curve enters a falling road at a junction, it is difficult to carry out any alteration. Apart from this point, "the radii of curves of roads used by fast traffic should, where practicable, provide the best possible and an unobstructed view; and where this is not possible, means should be provided whereby the approach thereto is in some way indicated."

Obstructions in Roads.—A matter which is noticeable on some roads is the placing of lamp standards or tramway poles to support overhead wiring in the centre of thoroughfares. This class of obstruction is not only objectionable to traffic and a source of danger, but it also materially increases the cost of maintenance. The road is made with a regular contour from side to side, but as these posts are placed at frequent intervals, they practically prevent the traffic using the centre of the road, which is in consequence not worn, and the traffic concentrates on the two sides. Traffic which is made to concentrate on a narrow width forms a track, and the wear is more severe than it would be if it was allowed to have the full width of the road surface; the road therefore requires more frequent repair, and still more on account of the difference in alteration of contour due to the centre of the road remaining as it was originally laid.

These obstructions necessarily slow up the traffic, because they cannot pass each other with the same ease they are able to do on a clear road.

The International Congress on this point has a resolution :—

"No obstruction of the public highway should be permitted, either by vehicles standing unreasonably or travelling at an obstructing speed, or by things placed on the highway."

There are, of course, necessary and advisable obstructions such as at dangerous junctions of roads or at curves where it is advisable to cause vehicles to keep to their own side of the road, and in very wide roads it does not seem unwise to provide occasional refuges with a lamp which not only acts as a refuge for foot passengers desirous of passing across the road, but may incidentally divide the road into three parts, the centre being monopolised by through fast traffic.

Meaning of "Heavy," etc., Traffic.—In this work there are many occasions when the terms "moderately heavy" or "heavy" traffic are employed, and it is somewhat confusing to know precisely what the terms mean.

The standards fixed by a committee of British road engineers, and submitted to the third Road Congress, were as follows :—

Light traffic=70 vehicles per day, including an occasional engine or heavy motor.

Medium traffic = 70 to 250 vehicles per day, including not more than 5 per cent. of engine, heavy motor, or similar traffic.

Heavy traffic = 250 to 600 vehicles per day, of which 5 to 10 per cent. is similar heavy traffic.

Very heavy traffic = above 600 vehicles per day, and not less than 10 per cent of similar heavy traffic.

TRACTIVE EFFORT ON SURFACES.

A number of experiments were carried out by Dr A. E. Kennedy and Mr O. B. Schuring of the Massachusetts Institute of Technology in 1916, with the object of compiling a record of the tractive effort required for various surfaces. The experiments were made by using an electric delivery van weighing less than half a ton and equipped with solid tires, roller bearings, worm drive, and differential gearing. Laboratory tests proved the mechanical efficiency of this machine from battery terminals to the wheel rims to be between 60 and 75 per cent.

Tar Macadam.—On tar macadam in good condition and wet, the tractive resistance east-bound varied between 27 lbs. at 12 miles per hour to 30 lbs. at 15·5 miles per hour; west-bound the tractive effort varied between 20 lbs. per ton at 10 miles per hour and 24 lbs. per ton at 14 miles per hour.

Asphalt.—On an asphalt road in fair condition the tractive effort of 20 lbs. per ton was required at 10 miles per hour up to 24 lbs. per ton at 15·5 miles per hour. With the asphalt in poor condition the tractive effort was increased by about 10 per cent. Eliminating the air resistance, a constant tractive effort of 17 lbs. per ton was required between 10 and 15 miles per hour on asphalt pavements.

Wood Pavements.—Similarly on wood pavements the tractive effort ranged from 22 lbs. per ton at 10 miles per hour to 24 lbs. at 14·5 miles per hour.

In general, eliminating wind effect, the resistance of wood-block paving was about 15 per cent. greater than that on asphalt.

Brick Paving.—Brick paving in good condition showed a slight increase in resistance over wood blocks, and with the bricks slightly worn the resistance ran somewhat higher. Tar macadam in good condition showed the same resistance as an ordinary water-bound macadam with a fine surface in good shape. A 50 per cent. increase resulted from a macadam road in poor condition through holes.

Heavily Oiled Macadam Roads.—The resistance of heavily oiled macadam roads was rather high, and between 7 and 13 miles per hour on a freshly tarred soft road the resistance varied between 32·5 and 35 lbs. per ton.

Gravel and Cinder Roads.—Gravel and cinder roads showed about 10 or 15 per cent. more resistance than good macadam.

Granite Blocks.—Granite-block paving proved to be the worst road for mechanical traction, a road of this type over a concrete base, but with sand and gravel interstices, showing two and a half times the resistance of asphalt or wood blocks, the resistance of a granite-block pavement with cement joints being about 60 per cent. greater than that of asphalt.

With a granite road the resistance increases with speed when the still air resistance is eliminated due to impact resistance. Asphalt, as stated, gives a straight line curve of tractive effort and speed between 10 and 15 miles per hour.

Tractive-Effort Table.—The following table is compiled from statistics that have been made public from time to time. They are evidently approximate, and may even be misleading unless we know the exact condition in which the road was at the time the tests were made, and whether allowances were made for air resistance.

It seems desirable that systematic tests should be made on specially selected roads with suitably designed bodies so that the effort might be defined accurately. It will be noticed how air pressure affects the figures by the example above; in one direction the tractive effort was about 20 to 25 per cent. greater than when the vehicle was travelling in the opposite direction.

TABLE III.

Road Surface.	Ratio of Tractive Effort
Asphalt road (level)	1·00
Wood pavement	1·20
Tarred macadam	2·00 to 2·50
Macadam (dry)	2·00 „ 2·50
„ (small hollows)	3·50
Sett-paved road (dry)	1·50 to 2·50
„ „ (wet and muddy)	3·00

The speed of the vehicle has an appreciable effect on the tractive effort. This is shown in the following table :—

TABLE IV.

TRACTIVE EFFORT IN LBS. PER TON.

Surface.	1 Mile per Hour.	5 Miles per Hour.	10 Miles per Hour.	12 Miles per Hour.	14 Miles per Hour.	15·5 Miles per Hour.	17½ Miles per Hour.
Railway	9	..	..	..	..	..	27·5
Tram rails	12	12·25					
Asphalt (good)	..	..	..	17			
„ (poor)	..	..	..	19			
Macadam (dry)	..	42	49	....	50		
„ (soft mud on surface)	..	77	92	..	100		
„ (small hollows)	..	63	..	..	75		
„ tar	..	..	..	27	..	30	
Wood paving	..	..	22	..	24		
Sett paving	..	..	..	42	50		
Concrete	..	..	31				
„ ⅜-in asphalt oil coat and screenings	.	..	51				

These tables demonstrate forcibly that if a road is dry clean and has a good surface the tractive effort is considerably reduced, and the nearer the surface approaches to that of asphalt the less power will be required to propel the vehicle and the benefit be in favour of the user. Equally will it benefit the authority that has the maintenance of the roads under its control, because the wear will be reduced with the tractive effort.

Fig. 3 shows in a graphic form the tractive effort required to propel a vehicle on a steel rail at various speeds, and also the comparative effort on asphalt and macadam. While it is impossible to expect road surfaces to be of steel, it is evidently desirable to try and attain, by means of cheaper material, a surface approximating to steel, and probably the nearest is asphalt and wood paving. It is clear that macadam is unsatisfactory, and from Table III. (p. 18) it is much worse when in a wet and muddy condition, and is equally bad when the surface is uneven.

Assuming that asphalt is the unit, then the tractive effort on macadam is from two to six times greater. It must not be assumed that if asphalt was substituted for macadam there would be a saving of half or five-sixths of the fuel used to drive the vehicle. The power developed by an engine is expended in a large degree in overcoming the resistances or friction in the bearings and transmission gearing, together with the resistance of the air on the body of the vehicle; but the reduction can fairly safely be said to save 10 per cent. of the fuel used in its propulsion.

Effect of Tractive Effort on Tires.—Tractive effort has a direct proportional effect on the wear of the tires; in consequence a reduction of

one-half to one-sixth of the tractive effort will have a proportional influence on the wear of the tires Tires are, however, more generally

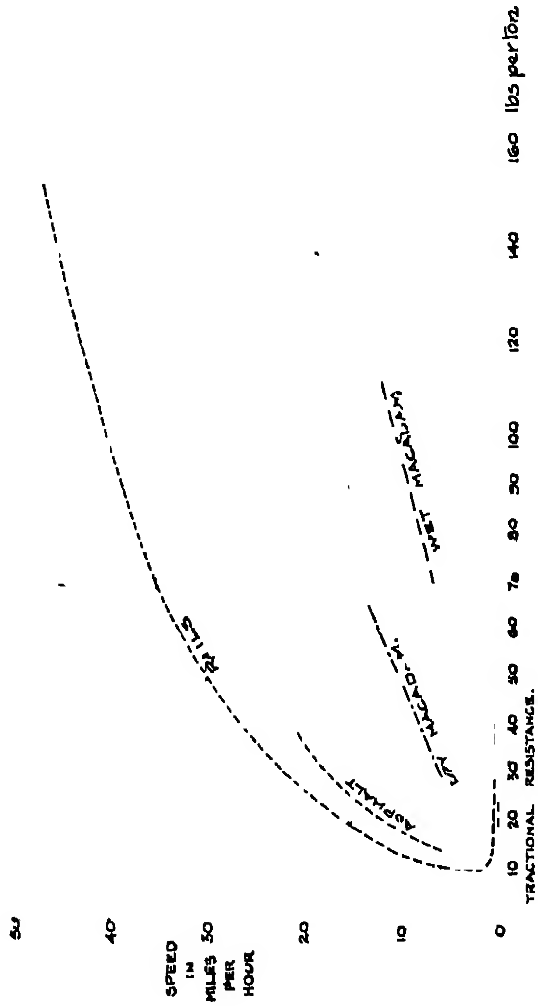


Fig. 3.—Tractional resistance

affected by the frequent sudden application of the brakes; apart from this wear, the results would be as suggested.

Uneven-Surface Effect on Vehicle.—Again, an uneven surface such as is common to macadam roads which are subjected to moderate or heavy motor traffic is the frequent cause of damage to the vehicle itself; the constant jarring will have an eventual effect on the engine, bearings, and

gearing, hence not only are repairs more frequent, but the life of the vehicle is shortened.

Economy resulting from Good Roads.—Taking the four items and assuming the percentages in the brackets as the saving to be effected by the improved and even surface such as would be given by asphalt, we have fuel (10 per cent.), tires (50 per cent.), repairs (20 per cent.), and depreciation (20 per cent.).

This is seen more clearly by a typical cost example of the running of a commercial vehicle prior to the war,[1] as shown in Table V.

TABLE V.

		Cost on Average Surface.	Improved Surface.
	d.	per cent.	per cent.
Tires	2	22	11
Petrol	1	11	10
Oil, grease, etc.	0·1	1	1
Registration, licence, etc	0·2	2·3	2·3
Establishment charges	0·45	5	5
Garage	0·45	5	5
Driver	1·7	19	19
Repairs	0·8	9	7·2
Depreciation	2·0	22	17·6
Sundries	0·3	3·7	3·7
			Surplus 18·2
	9*d.* per car mile[1]	100·0	100·00

The saving is represented by the item in the third column marked "surplus," and is placed under this heading separately, because it enables one to judge as to what amount could be placed under any other heading without increasing the cost, *e.g.* petrol before the war cost 9d. per gallon; it is clear that 1s. 9d. per gallon could be paid for petrol without it affecting the cost of running per mile if the roads had an even and regular surface.

Other Advantages.—There are other advantages which have not to be lost sight of: the average speed of the vehicle would be increased, because the delays would be reduced; with the reduction of repairs the need for "spare" vehicles are not so necessary; there is less damage to goods being conveyed.

Unification of Transport.—There can be little doubt that although motor transport on roads is a serious competitor to transport by rail

[1] The actual or present running costs of an army 3-ton lorry are, everything included, no more than 1s. 3d. per car mile.

(however rail transport may be improved, and it must be admitted that this is not only possible but probable), there will in the future be such an arrangement that both will work in conjunction with each other. It may be, also, that canals or inland waterways will be brought into more prominent use than hitherto; but the disadvantage which applies to rail or water transport is in the handling of the goods from one vehicle to the other. There is an advantage to some consignees in keeping the goods in the trucks at their sidings; but it is open to doubt whether this advantage is in the interest of the community, and if storage accommodation was available at the premises to which they are consigned, it would not require much alteration in the system of unloading the truck, which could be done whilst it formed part of the train. This would involve quicker handling at the various local stations, and would involve more vehicles being employed on the roads; but their use would be confined to the locality, and would necessitate improvement of the local roads.

From whatever point of view the subject is discussed, the need for improved road surfaces is apparent, and must in the immediate future demand attention.

Advantages of Asphalt Surface.—Roads with steep gradients are not usually paved with asphalt, on account of the lack of grip, or slipperiness but even these gradients may with some advantage be paved with asphalt because it is a surface that does not hold water very long, it dries out quickly, and it is free from mud, which is a factor of slipperiness; and further, in consequence of this quick-drying characteristic it is not so easily affected by frost, as in other cases a film of ice is seen on the surface, making it dangerous for traffic.

Effect of Wheels.—An examination has been made of the effect of *diameter of wheels* on the tractive effort. The following table shows the variation in the case of three wheels having different diameters:—

Diameter.	50 Inches.	28 Inches.	26 Inches.
Tractive effort (lbs. per ton)	57	61	70

And also in respect to the *width of the tire*:—

Width of Tire.	$1\frac{1}{2}$ Inches.	6 Inches.
Tractive effort (lbs. per ton)	121	98

The difference of the width on the various classes of material forming a surface does not seem to have any further decreasing effect. Tractive effort, *e.g.* the lbs. per ton required on hard macadam and loose macadam, increases in very small proportion.

Regulations as to Width of Tire.—In some countries regulations are made as to the width of the tires of all vehicles (horse drawn) which traverse the public highways.

In Bavaria the regulations depend on the number of wheels and the number of horses drawing the vehicles, and are as follows :—

Vehicle.	Drawn by Horses.	Width in Inches.
2-wheel cart . .	2	4·13
2 „ . .	4	6·18
4 „ . .	2	2 60
4 „ . .	3 to 4	4·13
4 „ . .	5 to 8	6·18

In Ohio, U.S.A., the regulations are dependent on the load :—

TIRES.

Load.	Width in Inches.
2500 to 3500	3
3500 „ 4000	3½
4000 „ 6000	4
6000 „ 8000	5
8000	6

In the United Kingdom the regulations are in the hands of the county authorities, and so vary in different countries; in some cases, also, there is a different weight for summer and winter use.

For example, in the case of waggons, the allowance in Cardiganshire for a 6-inch tire is 4 tons 15 cwts., in Shropshire the amount allowed is 6 tons, while in Lincolnshire it is 9 tons 5 cwts.

In the case of carts, in Cardiganshire the weight is the same as the above, but in Shropshire it is reduced to 3 tons 5 cwts., while in Lincolnshire it is brought down to 4 tons 6 cwts. These rules, however, are rarely complied with effectively.

Highways Act, 1878.—In this country there is the *Highways and Locomotives Act* of 1878, which stipulates :—

"It shall not be lawful to use on any turnpike road or highway a locomotive constructed otherwise than in accordance with the following provisions; that is to say—

"(1) A locomotive not drawing any carriage, and not exceeding in weight 3 tons, shall have the tires of the wheels thereof not less than 3 inches in width, with an additional inch for every ton or fraction of a ton above the first 3 tons; and

"(2) A locomotive drawing any waggon or carriage shall have the tires of the driving wheels thereof not less than 2 inches in width for every ton in weight of the locomotive, unless the diameter of such wheels shall exceed 5 feet, when the width of the tires may be reduced in the same proportion as the diameter of the wheels is increased, but in such case the width of such tires shall not be less than 14 inches; and

"(3) A locomotive shall not exceed 9 feet in width or 14 tons in weight, except as hereinafter provided; and

"(4) The driving wheels of a locomotive shall be cylindrical and smooth-soled, or shod with diagonal cross-bars of not less than 3 inches in width nor more than ¾ of an inch in thickness, extending the full breadth of the tire, and the space intervening between each such cross-bar shall not exceed 3 inches.

"The owner of any locomotive used contrary to the foregoing provisions shall for every such offence be liable to a fine not exceeding five pounds; Provided that the mayor, aldermen, and commons in the city of London, and the Metropolitan Board of Works in the metropolis, exclusive of the city of London, and the council of any borough which has a separate court of quarter sessions, and the county authority of any county, may, on the application of the owner of any locomotive exceeding 9 feet in width or 14 tons in weight, authorise such locomotive to be used on any turnpike road or highway within the areas respectively above mentioned, or part of any such road or highway, under such conditions (if any) as to them may appear desirable. Provided also, that the owner of a locomotive used contrary to the provisions of subsection 2 of this section shall not be deemed guilty of an offence under this section if he proves to the satisfaction of the court having cognisance of the case that such locomotive was constructed before the passing of this Act, and that the tires of the wheels thereof are not less than 9 inches in width."

It does not state what load has to be pulled, or what proportion

the width of tire of the trailer should bear to the load on the trailer; it also does not limit the number of trailers, so that the load per inch of tire on other vehicles drawn by the traction engine may be greatly in excess of the traction engine itself.

Note.—A Departmental Committee was formed and appointed by the Local Government Board in 1915 with the object of taking evidence and making a report on heavy motor traffic, and as to what extent such traffic damages highways, and whether the cost of such damage should be imposed on the owners of these vehicles or on the highway authorities. The Committee has a wide reference, and the results of the deliberations are briefly set forth in the following recommendations:—

"ROAD LOCOMOTIVES.

"The Committee do not consider that it would be desirable to reduce the permitted weight of traction engines, as any such reduction would increase the difficulties of dealing with the haulage of heavy loads, and while it is doubtful whether it would have the effect of reducing road damage to any appreciable extent in the case of lighter loads, it would undoubtedly tend to increase such damage in the case of heavy loads. Commercially it is impossible to prohibit entirely very heavy loads, say the Committee, and with such loads, heavier engines, if suitably tired, do less damage to the roads than lighter engines.

"**Wheel Bands and Cross-Bars.**—With regard to the construction of wheels of road locomotives, the Committee recommend that the tire of each wheel should be at least 5 inches in width, and that where cross-bars are used in driving wheels they should be placed at an angle which would secure that for at least one-half of the width of the tire there should always be one or two cross-bars in contact with the road surface.

"Theoretically, the statutory provisions in regard to the construction of wheels of locomotives seemed to be open to criticism, but the Committee state that the evidence did not appear to show that they were considered to be inadequate by road surveyors generally. One witness, it was true, suggested that the provisions should be reviewed, and submitted proposals somewhat on the lines of the regulations as to iron-tired heavy motor cars, having in view as one object the securing of a line of demarcation between the locomotive and the heavy motor car by fixing for the former a minimum wheel diameter of 5 feet, and a minimum width of tire of 14 inches. An examination of these proposals showed, however, that in the case of large diameter wheels of 5 feet and upwards the result

would be very much the same as under the existing provisions; and the Committee added that as the traction engine did not itself carry a load, there was not the same need for regulating width of tire according to axle load and wheel diameter as there was in the case of the load-carrying heavy motor.

"As regards narrow bands on steering wheels, several surveyors alleged that damage was caused to the roads by the use of these, though they did not all regard the matter as serious; and as it appeared from the evidence of the users and makers that the bands possessed considerable advantage in the case of both road engines and agricultural machines, the Committee did not recommend their prohibition.

"The damage caused to roads by locomotive traffic was attributed by several witnesses from the road and tramways authorities to the use of cross-barred driving wheels, and, while the majority of these witnesses considered that the cross-bars should be absolutely prohibited, others, recognising the difficulties of prohibition, proposed alterations of the size of the cross-bars or the spacing. Witnesses representing the traction-engine industry and the users of heavy agricultural locomotives were strongly opposed to prohibition. They described the proposal as 'impracticable' and 'impossible'; they contended that smooth wheels, which were the only alternative, would very materially reduce the hauling capacity of the engines, would be useless and dangerous on gradients and in certain conditions of the road, and that with such wheels the heavy agricultural locomotives could not be used about the farms and on the land. One witness asserted that 'the engines might as well be scrapped if we had to use smooth wheels.' The Committee were satisfied that serious damage was sometimes caused by the cross-barred driving wheels, and they considered that a strong case was made out for some amendment of the law in this respect. Total prohibition of the use of cross-bars appeared to us to be quite impracticable, but they were of opinion that an amendment could be made which, without seriously reducing the hauling capacity of the traction engine or restricting the use of the agricultural locomotive, would nevertheless render the cross-barred wheel less injurious to the roads.

"In making the recommendations already mentioned, the Committee expressed the view that the use of cross-bars should not be permitted on wheels of a smaller diameter than 4½ feet.

"**Springs.**—As to the suggestion that locomotives should be constructed with springs on the axles, the Committee said they considered that such a requirement was desirable as tending to diminish the vibration which was caused by the passage of heavy engines over the roads. Moreover,

the use of springs was compulsory in the case of all heavy motor cars. This requirement need not, however, apply to road rollers or ploughing engines.

"Locomotives which have been constructed in accordance with the provisions now in force should not, it is recommended, be required to conform with any new requirements as to construction.

"**Waggons drawn by Locomotives.**—The Committee regard as antiquated and unsatisfactory the provisions with regard to the weights which may be carried on waggons, carts, etc., drawn by locomotives, and they recommend that these should be repealed and new regulations substituted, based upon those applicable to vehicles drawn by heavy motor cars. They are of opinion that whatever may have been the reasons for the restrictions between cylindrical and non-cylindrical wheels, for prescribing in the latter case only varying summer and winter weights, and for requiring a width of wheel proportionate in the one case to the total load on the waggon (inclusive of the weight of the waggon), and in the other case to the weight on the wheel or pair of wheels (exclusive of the weight of the waggon), there was no adequate ground for retaining these distinctions at the present time.

"Several road surveyors suggested that the new provisions should be based upon the regulations governing the trailer of a heavy motor car which imposed a maximum limit upon the axle weight, and determined the width of the tire by reference to axle weight and wheel diameter. This suggestion, which the Committee had decided to adopt in principle, was not, as they understood, opposed by witnesses representing the traction owners and users, provided that no reduction was made in the weights permitted under the existing provisions. It was not, in the view of the Committee, practicable to require waggons to be provided with springs, their feeling being that it was preferable to encourage the use of springs by allowing additional weights on spring-mounted waggons.

"The Committee do not suggest any alteration in the existing provisions which limit the number of loaded waggons drawn by a locomotive or authorise the highway authorities to allow upon roads in their own areas the carrying of loads in excess of the weights ordinarily permitted.

"**Notice to Highway Authorities.**—It was represented to the Committee on behalf of the road and tramway authorities that the damage caused by the haulage of exceptionally heavy boilers and other pieces of machinery was at times irrecoverable, because they were unable to trace the party responsible for the damage and to establish a case against him. Witnesses proposed that the road authority should be notified in advance

of the intended use by such traffic of any road in its area. The suggestion generally made was that the notice should be sent to the county borough surveyor, or to the county surveyor, as the circumstances required, and that the county surveyor shall be required to notify the borough and district surveyor concerned. Some witnesses proposed that the notice should specify the road intended to be traversed and the day on which the traffic was to be expected; and some of them suggested that the road authority should be empowered to select the route to be taken. For a notice to a county surveyor 72 hours' notice was desired, for a notice to a county borough surveyor, 48 hours' notice.

"The traction-engine owners and users did not appear to object in principle to the proposed notice, but they pointed out that cases arose where they were unable to give a 72 or 48 hours' notice, or where they could not conform to a detailed notice specifying the particular roads and the particular day.

"The Committee ruled out as unduly restrictive the suggestion that the road authority should be empowered to select the route. It seemed to them to be clear that the notice, if it was to be of much value, must indicate the approximate route and the day on which the traffic might be expected; and further, that some provision must be made to cover the practical difficulties referred to by the users. The case would, they thought, be largely met if the regulations required such a notice to be given, and that wherever practicable the notice should be at least 72 hours to the county surveyor and 48 hours to the county borough surveyor, or, in the case of the metropolis, the city engineer of the City of London or the surveyor of the metropolitan borough council, and in any event notice should be given before the journey was commenced and before the engine was allowed to pass from one county area into another.

"**Speed Limits.**—The Committee see no reason for altering the speed limit of 4 miles an hour in the country, but express the opinion that the limit of 2 miles an hour in towns and villages is calculated to cause obstruction and congestion, and should be raised to 3 miles an hour.

"HEAVY MOTOR CARS.

"The Committee recommend that the unladen weight of the heavy motor car should be raised from 5 to 6 tons, and that the combined unladen weight of the car and trailer should be raised from 6½ tons to 8 tons.

"Other recommendations of the Committee under this heading are as follows:—

"(1) The definition of the unladen weight of a motor car should be amended.

"(2) The maximum laden weight and the maximum axle weight should not be altered.

"(3) The minimum diameter for wheels of heavy motors fitted with iron, steel, or other hard tires should be raised from 2 feet to 2 feet 9 inches, and a scale of minimum diameters should be prescribed, according to registered axle weight, where the registered axle weight exceeds 4 tons.

"(4) The edges of a tire of iron, steel, or other hard material should be rounded. Bevelled edges should not be permitted.

"(5) The diameter of any wheel of a heavy motor, which is fitted with a solid rubber tire or other tire of a soft or elastic material, not being a pneumatic tire, should not be less than 2 feet 6 inches. No regulation need be made as to the size or shape of the tire itself.

"(6) The existing law, which permits a motor car to be used to draw one trailer only, should be retained. Certain minor amendments should be made in the regulations relating to the use of trailers.

"(7) The present speed-limit regulations should be retained, subject to the following amendments, namely, (*a*) that the speed for a heavy motor car tired with iron, steel, or other hard substance should not in any case exceed 5 miles an hour; and (*b*) that where a heavy motor car draws a trailer and the wheels of both vehicles are fitted with rubber tires, the maximum speed should be 8 miles an hour.

"**Wheel Diameter and Tire Width.**—The Committee state that most of the witnesses who discussed the effect of iron and steel tires upon the roads expressed the opinion that an increased diameter of wheel was more important than an increased width of tire. They add: 'There appears to be no doubt that any substantial increase in the diameter tends to diminish the strain on the road due to the pressure of the loaded wheel. The reasons are obvious. In the first place, the use of wheels of large diameter increases the effective area of the road surface actually in contact with the wheels, thereby reducing the intensity of the weight pressure. In order to reduce the weight pressure, the area in contact with the road must be increased either longitudinally by an increase in the diameter or laterally by an increase in the width of the tire. Owing to the camber of the road, an iron or steel tire which is very wide does not secure effective contact for its whole width; the limit of width at which such a tire ceases to be effective is variously given by witnesses at 8 to 10 inches. On the other hand, assuming that the road surface is not absolutely rigid, it would seem that an increase of diameter is bound to result in an increase of the area in contact. In the second place, where

impact is set up by a vehicle in motion, the larger diameter tends to lessen the force of the impact, because at a given speed the larger diameter reduces the number of revolutions of the wheel, and that reduction of the wheel speed has the effect of diminishing the force of the impact. In the third place, on a yielding surface the larger diameter reduces the resistance which the vehicle has to overcome, and thereby lessens the strain on the road due to the effort the vehicle is making.

"'It is clear that on a yielding road surface, given the same amount of weight on the wheel, the small wheel penetrates more deeply, and the deeper the penetration of the road surface the greater the propulsive effort the vehicle has to make. On the other hand, it has been pointed out with considerable force that an increased diameter involves both an increase of the unsprung weight, due to the added weight of the wheel itself, and also an increase of the total unladen weight, due to the increase in the weight of the gearing and axle, rendered necessary by the increase in the diameter of the wheel. Moreover, there are difficulties in the way of a larger wheel from the point of view of the height of the platform for loading, and of the probable curtailing of load space. We are, however, strongly of opinion that the advantages of an increased diameter outweigh the disadvantages.'

"RESTRICTION OF HEAVY TRAFFIC ON UNSUITABLE ROADS.

"Concerning the restriction of heavy traffic on unsuitable roads, the Committee recommend that existing motor-omnibus routes should be left untouched, but that new routes to be established must have the consent of the highway authority, or, if that consent was refused or was given subject to unreasonable conditions, the consent of the Local Government Board. Powers should be conferred on the Local Government Board and the road authorities to regulate through heavy motor traffic in order to secure that such traffic was, as far as practicable, required to use the roads which were constructed to carry it. County councils should be given power to regulate traffic upon a road which was under repair or reconstruction, and to divert the traffic on to another road.

"The Committee express the view that the evidence which had been given as to the serious damage caused to a number of roads by motor-omnibus traffic, and the very heavy expenditure entailed in improving these roads to render them fit for the traffic, went far to prove that this traffic was exceptional in character, presented special difficulties to

highway authorities, and required special treatment. They are of opinion that much of the damage and expenditure might be avoided if there existed between the motor-omnibus companies and the highway authorities, both local and central, the closer co-operation which might be expected to result from placing motor-omnibus traffic under control. With closer co-operation it should often be found possible to abstain from using a road which was known to be unfitted for the traffic, or, if such a road must be used, to carry out the necessary works of improvement before the service had commenced, and consequently under more favourable conditions and at less cost.

"**Roads and Frost.**—Several witnesses for the road authorities suggested that there should be some power to prohibit or regulate heavy traffic so as to protect from damage roads which were for the time being unfitted for the traffic owing to the break-up of a frost. The Committee doubted whether any scheme involving restrictions of heavy traffic in such circumstances was feasible, and they added that the solution of the difficulty appeared to lie, mainly, in the provision of road surfaces which were not liable to be seriously affected by frost.

"SPECIAL QUESTIONS.

"The Committee desire to place on record their conviction that the question of the strengthening or reconstruction of privately owned bridges over railways and canals is one requiring immediate consideration with a view to legislation at the earliest possible date. They are also of opinion that the public demand for improved facilities for road transport requires that the Local Government Board, and in the case of railway bridges the Board of Trade, should have more direct control than is given by the present law and regulations, so as to secure that heavy motor traffic is not hampered by the placing of restrictions on the use of bridges which are not in fact necessary.

"It appears to the Committee to be very desirable that the public funds should be made available to encourage the design and construction of mechanically propelled vehicles calculated to cause less damage to the roads than some of the types at present in use. Facilities should also be given, by special licence or otherwise, to enable trials and demonstrations to be held of self-propelled vehicles which cannot ordinarily be used on the roads without breach of the law.

"**Scotland.**—As regards Scotland, it is suggested by the Committee that the law in force in England and Scotland should, as far as possible, be assimilated. The idea of the Committee is that where the provisions

in force are practically identical, amendments corresponding with those which it is recommended should be made in the English provisions should be made in the Scottish provisions."

Motor Car Act, etc.—The wording of the section dealing with this matter in the *Motor Car (Locomotives) Act*, 1903, is as follows :—

> "A heavy motor car may be used on a highway if the weight of the heavy motor car unladen does not exceed 5 tons, or if the weight of the heavy motor car unladen with the weight of an unladen vehicle drawn by it does not exceed 6½ tons.
>
> "The registered axle weight of an axle of a heavy motor car shall not exceed 8 tons, and the sum of all the axles of a heavy motor car shall not exceed 12 tons."

The Act further stipulates that the tires shall be flat and they shall have rounded edges. The tires may be plated, provided the spaces between the plates in the course of a horizontal line do not exceed altogether the width of the tire.

> "The tire shall not be less than 5 inches in width.
>
> "The unit of axle weight may vary according to the diameter of the wheel.
>
> "For a wheel 3 feet in diameter, the unit shall be 7½ cwts., and 1 cwt. is allowed for every 12 inches excess diameter over 3 feet.
>
> "And if less than 3 feet, the unit shall be decreased 1 cwt. for every 6 inches below 3 feet."

The reason of this increase of unit is to be found in the larger area that would be in contact with a road surface with the increase of the diameter.

> "The axle weight of a trailer shall not exceed 4 tons.
>
> "The regulations applying to the tires of heavy motor cars apply also to the tires of trailers."

Table VI. gives the smallest tire and the largest tire for wheels of different diameter and maximum load on the axle :—

TABLE VI.

Diameter of Wheel.	Width of Tire.	Weight of Load on Axle.		Width of Tire.	Weight of Load on Axle.		Unit of Axle Weight.	Speed.
	inches.	T.	C.	inches.	T.	C.	cwt	
2 ft.	5	2	15	15	8	0	5½	Eight miles per hour or to 5 miles per hour if the car exceeds in weight 3 tons unladen, or has an axle with an axle weight exceeding 6 tons, or draws a trailer. There are exceptions allowing higher speeds to cars fitted with pneumatic tires or tires of a soft or elastic material.
Trailer	3	1	13	7½	4	0		
2 ft. 3 in.	5	3	0	13½	8	0	6	
Trailer	3	1	16	7	4	0		
2 ft. 6 in.	5	3	5	12½	8	0	6½	
Trailer	3	1	19	6½	4	0		
2 ft 9 in.	5	3	10	11½	8	0	7	
Trailer	3	2	2	6	4	0		
3 ft.	5	3	15	11	8	0	7½	
Trailer	3	2	5	5½	4	0		
3 ft 3 in.	5	3	17½	10½	8	0	7¾	
Trailer	3	2	6½	5½	4	0		
3 ft. 6 in.	5	4	0	10	8	0	8	
Trailer	3	2	8	5	4	0		
3 ft. 9 in	5	4	2½	10	8	0	8¼	
Trailer	3	2	9½	5	4	0		
4 ft.	5	4	5	9½	8	0	8½	
Trailer	3	2	11	5	4	0		
4 ft. 3 in.	5	4	7½	9½	8	0	8¾	
Trailer	3	2	12½	5	4	0		
4 ft. 6 in	5	4	10	9	8	0	9	
Trailer	3	2	14	4½	4	0		
4 ft. 9 in.	5	4	12½	9	8	0	9¼	
Trailer	3	2	15½	4½	4	0		
5 ft.	5	4	15	8½	8	0	9½	
Trailer	3	2	17	4½	4	0		
5 ft. 3 in.	5	4	17½	8½	8	0	9¾	
Trailer	3	2	18½	4½	4	0		
5 ft. 6 in.	5	5	0	8	8	0	10	
Trailer	3	3	0	4	4	0		

The rules do not apply to pneumatic tires or those made with a soft or elastic material; no width is specified, as the practical necessities in such cases will doubtless be enough to secure the selection of tires of suitable strength and durability and hence of adequate size.

A trailer does not require registration.

The weight must be printed in prominent letters on the vehicle :—

U.W. . . . tons, *i.e.* unladen weight.
A.W. . . . ,, cwt., axle weight.
Speed . . . m.p.h., maximum speed.

Actual Examples.—These regulations are necessary, and are undoubtedly enforced in the case of the unladen vehicle, but it is very doubtful whether the axle weights are ever tested subsequently, when the vehicle is loaded and being used. One example came under the

3

notice of the writer. The back wheels of a loaded Foden steam motor waggon, when passed over a weighing machine, registered 9 tons 15 cwts. 1 qr., whereas the maximum axle weight for this vehicle is 8 tons —the actual weight being about 20 per cent in excess of the weight allowed. Another example recently showed 12 tons on a 4-wheeled trailer, wheels 2 feet 6 inches in diameter, 7-inch tread—*i.e.* 50 per cent. in excess of the regulations of the Act.

Regulations of International Road Congress.—The general rule that the weight on a tire per inch of width should not exceed 7½ cwts. is one that was approved by the International Road Congress at Paris in 1908, and confirmed at Brussels in 1910—although one delegate was of the opinion that the weight was too high It is undoubtedly advisable to consider, as is done in the Motor Car Act, the diameter of the wheels, and proportion the weight so as to encourage the use of a large wheel in preference to a small one.

The speed and weights that were suggested at the International Road Congress are as follows :—

"SUGGESTIONS OF THE INTERNATIONAL ROAD CONGRESS, WEIGHT OF VEHICLE, ETC.

"(A) Public-service automobiles cannot cause appreciable damage to the road provided that the maximum speed does not exceed 25 km. (15·5 miles) per hour; the maximum axle load does not reach 4 tons on the heaviest axle, and that with wheels of 1 metre (3 feet 3 inches) diameter the load is below 150 kg. per centimetre width of tread (825 lbs. per inch of tread).

"(B) Industrial automobiles need not cause exceptional damage to a well-constructed road provided the following limits are adhered to :—

"First type : vehicles in which the axle load is less than 4½ tons :

Maximum speed 20 km. per hour = 10½ miles per hour.

Load on tires = 150 kg. per centimetre of width of tread of 1 metre diameter = (825 lbs. per inch of tread).

"In the narrow streets of towns and large cities, when vibrations of the ground are to be feared, it is possible to minimise the inconvenience by reducing the speed in a suitable proportion.

"Second type : vehicles in which the maximum axle loads are between 4½ and 7 tons :

Maximum speed = 12 km. per hour (7½ miles per hour).

Load on tires = 150 kg. per centimetre of width of tread with wheels of 1 metre diameter.

"Provisionally and under reserve of the results of further experiments, when the diameter of wheels is above 1 metre the load per centimetre width of tread should be calculated for both types of vehicles and also for such as are described in paragraph (A) by using the formula.

$$C=150\sqrt{d}$$

where d=diameter in metres and C=the load in kilograms.

"It is desirable that experiments should be undertaken in order to determine the maximum width which can be given to the tires of all automobiles, while still ensuring that under normal conditions the distribution of the load on the ground should take place over the whole carrying area.

"(C) Ribbed or grooved iron tires cause abnormal damage to the road, no matter what their width be or what load they support.

"(D) Vehicles propelled by mechanical power cannot cause extraordinary damage to the curved portions of roads provided that at these points a sufficient super-elevation is given and that the curved portion is not approached or traversed at an unreasonable speed.

"(E) With a view to saving the roads, it is desirable that the car-builders go carefully into the question of clutches and brakes, so that the skidding of the wheels may be avoided; that they also balance the motor as perfectly as possible, and that they allow a reasonable raising of the centre of gravity."

Frictional Resistance of Horse's Hoof and of Motor Vehicle compared.—It is not the wheel or the weight of the load on the wheel that damages the road so much as horses' shod feet. In the case of a horse-drawn load weighing 4 tons, the frictional resistance is about 200 lbs., and if it is the case that a horse has always two feet on the road when in the act of drawing the load, the horse foot exerts a force of 100 lbs., or about 30 lbs., to the inch of calkin. If the motor vehicle is considered in comparison, the 200 lbs. is transmitted to two wheels and is spread over a further area, *i.e.* the portion of the wheel tire in contact with the road surface is about 6 inches × 3 inches, therefore the frictional resistance would be about 6 lbs. per inch, or about one-fifth of the effect of the horse's shoe.

Rubber Tires.—Since the regulations that have been quoted were enacted, there has been a change in the material forming the tires of vehicles; and in the making of new regulations, which will have to be taken in hand in the near future, if possible, encouragement will, no doubt, be given to rubber-tired wheels, and less encouragement to studded tires than to tires composed wholly of iron.

Tires more Resilient than Road Material.—Road engineers would

welcome any tire composed of material more resilient than the material forming the surface of the road, as obviously such tires will have a less wearing effect than where the reverse is the case.

Whenever regulations are enacted, the licensing authorities should exercise the power that is given to them to see that the regulations are carried out when the vehicles are being used and at work.

Set of Wheel.—What would seem to be a very important point that has been left out of consideration is the *set* of the wheel. If the vehicle is designed to fulfil the above requirements in regard to the weight of the vehicle and the weight on the axle, a stipulation should also be made that the wheels should be so set or shaped that the surface of the tire should be in constant contact with the surface of the road on which it has to travel. The weight per inch of tire was obviously laid down with a view of spreading the weight over a large surface of road, *i.e.* the full width of the tire; but the wheels of these motor vehicles

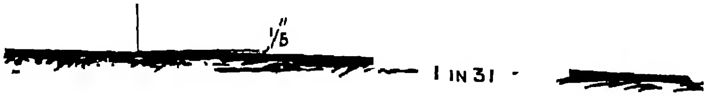


Fig. 4.

are designed to run on a level plane, whereas every road has a considerable contour or curve, and while one wheel in certain circumstances may be in full contact with the surface of the road, the other will touch the road for only about one-third of its width.

Recently, on an asphalt road, a motor waggon was traversing the surface, and one wheel was only in contact to the extent of 2 inches out of the 7 inches width of the tire, and the pressure was therefore at the rate of three and a half times greater than the Act allowed, and the edge of the wheel was cutting into the asphalt.

There must have been not only a strain on the road but also on the axle, as the wheel is designed to transfer the load at right angles to the axle, whereas it was being transferred at an angle less than a right angle, causing excessive wear on the two opposite sides of the axle bearing, and eventually developing a wobbling motion in the wheel.

In a perfect road surface the wheels of such a vehicle would never be in full contact with the surface of the road, and the two diagrams (figs. 4 and 5) show in one case, on a surface with a contour of 1 in 31, the outside of the wheel is off the surface of the road to the extent of

$\frac{1}{8}$ of an inch, while in the other case, where the surface has a contour of 1 in 14, the outside edge of the wheel is off the road to the extent of $\frac{1}{3}$ of an inch.

Cutting of Asphalt.—These figures are sufficient to show that the pressure, in such constructed vehicles, is not evenly transferred to the road surface, and explain the cutting of the asphalt surface which has been so prominent on many roads, and which has been much more in evidence since the advent of motor traction.

It is difficult to understand why the question has not been considered, because it has previously been the custom with horse-drawn vehicles to set the axle of the wheel at an angle to the axle bed, and a careful examination of a number of horse-drawn vehicles shows that the tires are sometimes more worn on the inside or the outside, depending on whether the average contour of the road on which

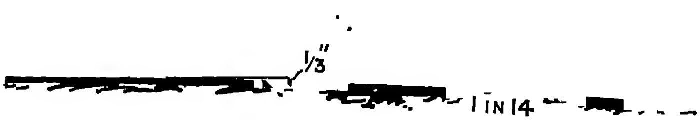


FIG. 5.

the vehicle has been in the habit of traversing has been greater or less than that at which the angle of the axle has been set. It has been suggested to the writer that the wheels are set vertical to the axle, so that when the load is placed on the vehicle it allows of a "drawing-in" of the wheels inwards, thus allowing the tires to adapt themselves to the road surface and be in full contact. This is, of course, neither sound theory nor good practice. If such a case did actually occur in practice, it would cause a pinching-in of the road composition, and a strain which would tend very rapidly to deteriorate the best pavement.

There is no insuperable difficulty in constructing the axle bearings so as to allow the wheel to conform to the contour of the road; it may add to the cost of the construction of the vehicle to some extent, but the advantage both to the vehicle and to the road would offset such extra cost. If road authorities were assured that the tires were always in full contact with the road surface, there would probably be a more generous view taken of the loads that should be placed on the vehicle.

Mr A. E. Collins, M.Inst.C.E., in a very able article in vol. xlii. of the *Journal of the Institution of Municipal and County Engineers*,

indicated by diagrams three different methods of construction of the driving wheels of heavy vehicles which would automatically conform to the contour of the road.

Camber of Roads.—There is no doubt that a curved contour is not as desirable for traffic as a perfectly straight and level surface from side to side, but it will be found that many macadam roads have been built with a contour similar to that shown in fig. 6, which gives a curved contour neither a strict arch nor barrel-shaped—it is almost flat in the centre, and more quickly slopes as it approaches the channel.

The camber of a road has to be varied on account of cross falls, gullies, crossings, etc., and so it is usually the case that when the centre of the road and the channels are laid out, the remainder is curved more or less to the above shape as the eye directs.

By such a curvature a vehicle is encouraged to traverse a greater width than might otherwise be the case, and might with advantage

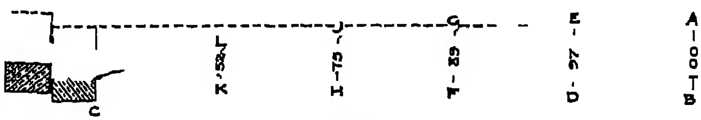


Fig. 6.

B C=30 feet. D E=0·97. H J=0·75.
A B=1 foot. G F=0·89. K L=0·52.
CK=K H=H F=F D=D B

to itself and the road have the wheels set at 1 in 36. By this alteration the wear on road and on the tire would be decreased, and there would be less tendency to skid.

Skidding of Vehicles.—The skidding of motor vehicles is worth inquiring into from this point of view.

It must be obvious that the set of the wheels in a line at right angles to the axle bed encourages skidding; the weight of the vehicle is transferred to the inner edge of the wheel, and this is balanced by a force at right angles to the surface of the road and a second force along the tangent to the curve from the centre of the vehicle outwards. When the vehicle is placed with its wheels equally distant from the centre of the road, the tangential forces act in opposite directions and thus balance each other, and the vehicle takes a straight course; but when the vehicle is wholly on one side of the road, the pressure of the load is more on the "near" or the lower-placed wheel than on the off or higher-placed wheel, and therefore the tangential force is greater. Thus, if the surface of the road is inclined to be greasy, and the surface of the tire not in full contact, there is a tendency for the vehicle to slide towards the kerb, until the forces are balanced.

Points for User.—The adaptation of the tire to the road must reduce the wear, as otherwise the tire is continually in shearing until it adapts itself to the conditions of the road, as is the case with wheels shod with rubber tires.

There are thus a number of rules which the designer and user may with advantage make use of, and which, if followed, would tend to render the task of the road engineer less onerous.

Cost of Repair.—It has to be remembered that whatever expense a local authority may incur in the matter of the repair of the road, the user has eventually to pay a considerable proportion of the cost, and so should make whatever adaptations are possible.

The Departmental Committee that is inquiring into the question

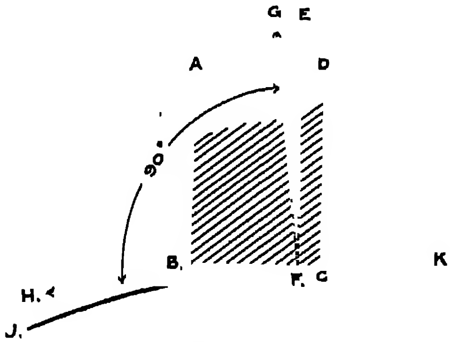


FIG. 7.

J O K represents surface of road.
A B O D represents the wheel of vehicle.
B F, direction of load.

F G and F H, the direction of the resolved forces, F H being a tangent to the curve at the point F.

of heavy motor vehicles will probably make a searching inquiry into these various matters. The points raised may not appear to be of much importance when considered in relation to one vehicle; it is, however, these small matters that become large and important when they are multiplied by thousands.

New Arterial Roads.—A considerable amount of attention has been devoted to the problem of providing new main or arterial roads, and while it scarcely comes within the purview of a work which obviously is intended to deal with the engineering or constructional part of roads, it is perhaps not out of place to mention the matter in the introduction.

The first work carried out in opening up a new district is the formation of a road from the nearest town or district in which roads are already built. The motor has, in a sense, discovered in an old country new areas; the old roads serve part of the purpose of opening up these areas, but they are often too narrow, frequently too circuitous, they may have

so many bends and bottle necks, etc., as to become unsatisfactory, and in consequence either entirely new roads, bye-pass roads, or important widening schemes must be provided to satisfy the requirements. Where there is a proved necessity, the various proposals have to be examined by the authorities as to their cost, their effect on the districts which they may avoid, etc., and generally into their merits.

Local Interests.—The questions raised are not easily disposed of: local interests of all kinds are at once brought forward in opposition, and the active construction hangs for a long period while these questions are disposed of.

Town Planning and Road Improvement Acts.—Under the Town Planning Act of 1909 and the Development and Road Improvement Act of the same year, new roads can be actually formed or proposed on paper, the lands through which any road is proposed to pass can be sterilised, *i.e* after the date of notice, the owner of the land is prohibited from erecting upon the area proposed to be used for the road any permanent structure. Whenever it is thought necessary the road can be constructed. Further, land may be purchased on either or both sides of the proposed road, and whatever increased value may accrue by reason of the road being so constructed through the land, the land so purchased can be resold and by this means the cost of the road may be recouped to some extent.

These two Acts are, or could be, made to be a complement of each other; where the powers are lacking in the one case they may be said be provided by the other; it only seems to require an agreement veen the authorities which administer these Acts to effectuate the)osals.

No actual instance of a new road being carried out on these lines .s been, to the knowledge of the writer, dealt with as yet. On the other hand, new thoroughfares have been built in a few cases under the Town Planning Act or local Acts of a similar character, and in a few other cases a town-planning scheme has been designed and the lands sterilised.

Defects in Town Planning Act.[1]—Under the Town Planning Act,

[1] Under the Housing, Town Planning Act, 1919, amendments to the Act of 1909 have been made, and it is now the case that any local authority may prepare a town-planning scheme without having first to obtain the sanction of the Ministry, and every borough and urban district with a population over 20,000 must prepare a scheme by 1st January 1926 The Ministry can before that date require a scheme to be prepared by a local authority where they consider this course necessary. Local authorities should from the outset consider the town-planning needs of their district with a view to making a complete town-planning scheme as time allows. The procedure in connection with the making of a town-planning scheme has been simplified by the new Act.

schemes have to be submitted to the Local Government Board and approved, and certain expenses are incurred. These schemes may be ill timed, *i.e.* many years may pass before development will take place in the district, and therefore unnecessary expense is involved. It would seem desirable that the whole of the authorities should have the power to lay down the site of a road, or increase the width of a main thoroughfare, without having recourse to an Act which is only permissive and not compulsory, because there are obvious arguments which would show that such a scheme may actually prevent the immediate development of the land in the district, and send those who wish to build upon it into other areas where the restrictions are not so far-seeing.

Future Roads.—In the future, it will be the case that either new roads will be made or the existing roads will be greatly improved or bye-pass roads constructed to enable traffic to pass round a town at which it has no reason to call, and thus relieve the town of a certain proportion of traffic which might otherwise cause a congestion. Local interests are found to be opposed to new roads and bye-pass roads, because they are likely to take away from the frontages on the old road or from the town chance customers, *i.e.* persons who, although they may have no immediate object in visiting the town, may call and make purchases, etc. But there can be little doubt that such roads are, or will become, necessary for commercial traffic, and the roads must be made so as to cater for future requirements, and apart from local interests.

Whether the time is or is not ripe for these new roads is a question of the amount or volume of traffic and for the general opinion of the locality.

Effect of Motor Traffic on Congestion.—There are a number of cases where a few years ago a road was obviously too narrow and congested, but since motor traffic substituted horsed traffic to a large extent, these comparatively narrow roads do not appear to be so congested, mainly on account of the increased speed of the vehicles and the heavier loads they carry, thus requiring fewer vehicles to occupy the road.

On the other hand, the time will come when the traffic will increase and the narrow roads will once again appear congested and necessitate increased width—or new roads, as suggested above.

Width of Roads.—A diversity of opinion is noticeable in the discussions that have taken place on these new roads as to what width is the most desirable and as to what should be provided in the road.

The business man says they should not be very wide. His opinion is that a person walking along the pavement of one side of the street should have a good view of the premises and goods placed in shops on the other side of the road. He points out that the best business

or shopping centres are in narrow roads; from which one could argue that wide bye-pass roads round the town are desirable, and those in shopping centres should be left comparatively narrow, then, as has been pointed out, this deprives the same business man of the chance customer, so that it is evidently difficult if not impossible to satisfy all parties. The widths that have been suggested vary from 80 to 250 feet

Circular Roads.—These are striking illustrations of very wide circular thoroughfares, such as that in Brussels, which almost makes the circumference of the city; but in this case a great portion of the width is taken up by a boulevard, and such a road with such a feature is an asset to the city; but the actual road widths are not nearly so great as 200 feet. Probably a total width of from 80 to 100 feet is sufficient for all traffic requirements, especially having regard to the fact that where the main roads had such a width the obstructions or hindrances from other traffic would be so small as almost, if not entirely, to be negligible, hence the average traffic speed is greatly increased.

We have been so accustomed to slow traffic and to obstructions in narrower roads, that we are apt to exaggerate the requirements under faster conditions, improved surfaces, and freedom from obstructions.

Congestion at Junction of Roads.—The real difficulties of traffic congestion are due mainly to the slowing up of traffic as it turns into other thoroughfares, at bottle necks, and by vehicles standing at business premises. There would be great advantages to the road as a whole by improving the methods at junctions, dispensing with bottle necks, and a width of 80 feet would allow for vehicles to stand at business premises in roads not provided with tramway tracks.

As to what should be provided in the roadway is a question that has been equally discussed at length. Suggestions have been made that slow traffic, fast traffic, tramways and cycle traffic should each have their separate tracks; in other cases, that tramways should be eliminated or given a specially allocated area, or that they should either occupy the middle or the side of the roadway.

Tramways in Roads.—From a road-engineering point of view, and from the point of view of the general road-user, tramways are a source of great annoyance and trouble. They are undoubtedly of value to a considerable proportion of the general public, and undoubtedly were a distinct boon under horsed-traffic conditions, but few people would, to-day, with their alternative experience of motor buses, say that the general travelling public would not prefer the moto rbus to the tramcar.

During a period of three months, the writer tested the speed efficiency of the motor bus and tram on the same road over a distance of $1\frac{1}{2}$ miles;

for the greater part the road was of ample width, and the traffic had a free run, but for ¼ mile of its length the road narrowed and the traffic was heavy. From fifty consecutive tests where the motor bus started after the tram had got some distance on its way, there was only one case where the tram arrived first; on two occasions they arrived simultaneously, and on the remainder the tram was hopelessly beaten.

Tramways as a rule occupy the best portion of the roadway, *i.e.*, the centre, and thereby the public have to step over a portion of the road to the tramcar, with danger to themselves from passing traffic; this is an obstruction to the traffic. The general traffic, where the trams have a frequent service, are debarred from using the centre of the road; hence if by reason of the general traffic increasing to such an extent that the road has to be widened, the tramways are placed still further from their passengers.

Effect of Tram Rails on Wear of Road.—One of the features of a tramway track in a roadway is the steel rail; the wear of steel is infinitesimal, and as it is placed in the road surface, composed of totally different material which wears in an observable degree, it necessarily follows that it will not be long before the rail will stand up above the general surface of the roadway. Granite setts are the least affected of any of the pavements that are used; but it is admitted that such a pavement is very noisy, the joints hold a certain amount of grit or mud, and in large towns they are not considered a suitable form of pavement. In one case, the writer understands that chiselled granite setts with fine joints (⅛ inch) are used; such a pavement costs about £2 per superficial yard, and this pavement answers the purpose; but in general such a pavement would be considered as much too expensive, however long it might last. Wood pavements are therefore demanded, and in many cases adopted; here the difficulties become apparent, for the wear of wood paving is such that, under heavy traffic and in a roadway where it is free from tram rails, it may be allowed to wear over 2 inches before it is replaced. But where the rail is inserted in the pavement, the renewal must obviously take place at a very much earlier period, otherwise the rail would be appreciably above the general level of the road and become a source of danger; hence the cost is at least double what it would be in the ordinary road, and it thus becomes an expensive form of pavement.

In roads in which tram rails are placed, asphalt has not been tried to any serious extent in this country; it is, however, extensively used in Germany, and there seems no valid reason why it should not be used here. The wear of asphalt is about half that of wood pavements, but it has not been found easy to make a good joint with the tram rail—a special mixture has usually to be made. Asphalt is laid usually about

1 inch thick on a bituminous base, and one of the advantages of using asphalt is that the material that is left on the surface before it is renewed can be removed and reused, hence the expense is not so great as it would be with other pavements. At the same time, the very fact that a steel rail is in the surface of a road composed with other material of more rapid wearing capacity, involves extra cost to the whole of the remaining surface above that of roads in which tram rails are not laid.

Railless Cars.—In some districts railless cars are run by electricity provided at a generating station, but perhaps the greatest competitor of the tramway is the motor bus.

It has been demonstrated in previous pages that the wear of a road by motor bus is not any more than would be the case by other vehicles. Since they were installed in London, the pavements have shown a decrease in wear over what was apparent under horsed bus traffic.

Motor Bus preferable.—In consequence, if from every point of view the motor bus can be run as economically as the tramcar and can give similar satisfaction in regard to the carrying capacity, it should be preferred to tramways. The advantages are that they are able to change their route, in dense traffic they are actually faster than tramways, and they are available to the passenger at the footpath itself.

The tram rails themselves, when they become worn, are a source of trouble to ordinary vehicles, the wheels of which are frequently damaged by becoming fixed in the groove.

Tramways outside Road Area.—From these and other considerations of a minor character, the proposal is made by many that tramways, where they are to be installed, should be in an area divided entirely from the roadway surface.

International Road Congress on Trams and Buses.—The conditions for the use of public-service conveyances other than tramways were considered by the International Road Congress, which passed the following resolution :—

"The Congress is of opinion that public motor omnibus service should be encouraged. That it is difficult at the present moment to decide definitely on the respective advantages of the two modes of transport, but that one forms the complement of the other and not the rival, and the adoption of one or other method largely depends on local conditions.

"The progress of the motor omnibus and extent of the use of this method of transportation is capable of great extension—

(*a*) by the use of wheels fitted with rubber tires ;

(*b*) by any progress made in construction.

"The number of passengers carried by motor omnibuses should be greater for the town than for the country.

"In the study of new roads to be constructed in the neighbourhood of large towns as well as in the open country, it may be useful to try, if it does not interfere with the general interest, to provide a sufficient road width for the construction of a light railway outside the roadway. The trace, the gradients, the designs of cross sections will be, according to the requirements, determined in such a manner as to reserve all the facilities and necessary safety for every kind of traffic.

"It is desirable that the supplementary costs should be defrayed by the concession-holder or the constructor of the light railway, so far as the part of the road reserved for the rail track is concerned.

"The construction of sunken rails in the metalled roadways are always harmful to the viability of the roads, and there results a marked increase in cost of maintenance. It is desirable that this method should be avoided as much as possible.

"The establishment of rails for tramways in paved roads makes the repair of the paving very difficult when abutting against the rails. It is necessary to diminish the nuisance as far as possible by appropriate methods.

"Where the railway is placed by the side of the road it is preferable, where the width of the road permits, to construct it on a special track, inaccessible for wheel traffic and super-elevated for greater safety. It is necessary in all cases to provide proper drainage.

"If it is a case of metalled roadways, the concessionary or constructor of the railway should be obliged to construct on the outside border of the free roadside sufficient depots for materials for the repair of the road. The same obligation should in some cases be extended to paved roads.

"The removal of trees along roadsides should not be tolerated unless in extraordinary cases. If the width between the tree rows is insufficient for the rail track to maintain the recognised width for ordinary wheel traffic, the track should be laid outside the trees.

"It is desirable that the concessionary of light railways should undertake the duty of maintaining the area of the road or roadway occupied by the rails or contiguous to same, or pay the costs of maintenance.

"Apart from exceptional cases depending on local conditions, the construction of trackways in paved roadways can only be considered an expedient.

"Except where it is possible to provide special reserved spaces, tram tracks are best placed in the centre of the roads, and where so

placed, it is desirable to provide space on either side for two tracks of vehicles.

"The main traffic roads should be so designed that spaces are provided for tram tracks, fast and slow traffic, and standing vehicles; and in such a way that they can proceed without unduly mixing."

On the problem of new roads the following resolution was also agreed to :—

"As a general principle, it is better that new main roads be constructed to pass outside rather than through towns, and where an existing main road passing through a town is unsatisfactory for through traffic, it is often better, in preference to widening an existing narrow main road through the centre of a town, that new roads should be planned according to the science of town planning."

Junctions of Roads.—It may be that in the future the junction of two principal roads should be made so that one road passes under the other, just as has frequently to be done on railways, where the delay to the traffic is of serious moment.

ROAD MAINTENANCE.

British Isles.—The maintenance of the main roads in the British Isles is mainly the charge of the county councils, except where they pass through county boroughs, towns of 50,000 population or over, in which case the whole of the roads are controlled and maintained by the borough; but in the majority of those cases where the roads pass through other towns, the local authority usually maintains the main roads, and the cost of such maintenance is refunded either as a whole or the greater part by the county council to the local authority; in the latter case, it is argued that as the local inhabitants use the main roads for local purposes, they should therefore pay for the local use of the road, just as if the main road was actually a local road; in other cases there are main thoroughfares which are not considered as main roads, and no allowance is made. In some cases the county authorities maintain the main roads themselves, and do not delegate the repair to the local authorities.

On the whole the system, which appears somewhat complicated, is simple and works satisfactorily under ordinary conditions, but at the present time, when the roads obviously require reconstruction and there is a large area of roads in an unsatisfactory condition involving extra heavy taxation, State aid is being demanded to enable reconstruction to be carried out, after which, no doubt, the system of maintenance could easily continue, as the cost would be materially less than it is at the present time.

France.—On the other hand, there are some who wish to see the main thoroughfares come under the State, as in France, where the "Routes Nationales" are, both as to construction and maintenance, under the control of the Minister of Public Works, the administration being delegated to the Département des Ponts et Chaussées. The other subsidiary or bye-roads are controlled by the local authorities. There was evidently an element of dissatisfaction in this system from one cause or another, because it was anticipated up to the time that motor traffic began to make itself felt, that the centralisation of the roads would be altered and that even the Routes Nationales would be decentralised; but apparently it was anticipated that motor traffic would damage the roads to such an extent that the cost would be a serious factor for the local authorities, or it was realised that motor traffic had brought into existence new problems that it was desirable to realise what it meant in the national welfare; whatever may have been the cause, the fact remains that any such idea has now been abandoned.

Germany.—Germany is divided into kingdoms or provinces in which generally the principal roads are State roads, which are maintained by the State; but the administration of roads generally is not on uniform lines throughout the country, the system varies considerably in the different States or provinces. In some few cases there has been a tendency to transfer the main roads to the smaller unions, but in some of the larger States there has been a strong tendency to obtain control of even the bye-roads.

Belgium.—In Belgium the State roads are controlled by the administration of the "Ponts et Chaussées," but the provincial roads are under the control of the provincial authorities, and similarly the parish roads are maintained by the local authorities.

United States of America.—In the United States of America, the country being divided into States, naturally each State has its own idea of the methods which should be adopted in regard to road administration; the State of Massachusetts stands out as one which controls and maintains the principal highways.

State Control.—State control has its advantages and its disadvantages; theoretically the advantages outweigh the disadvantages, but it is very doubtful whether in practice it actually is so. It appeals, mainly from the point of view of finance, to many districts which are sparsely inhabited and where the rateable value in comparison with the mileage of roads is low. In the British Isles there are, as has been mentioned, counties which include large towns and small towns, but when the large towns have a population of 50,000, they can apply for the status of a county within its own area; thus the county of which it

previously formed a part is deprived of the rateable value of that town for the maintenance of its roads and for other purposes, and the remaining area may, if adjustments are not made, be subjected to somewhat heavier taxation if the roads in particular are more severely treated by a great increase in traffic and financial assistance thereby becomes necessary.

State control, however, is not desired when it becomes a question of the active management of the roads; there is a strong feeling against it, and this is caused by the impression that the State is a non-competitive body, there is no spirit of emulation, as is now the case where districts compete with each other, there seems to be no incentive, no encouragement to new ideas and methods, which are discouraged or looked upon sceptically, especially if they come from any person or body outside the State Department. There is the impression also that the State is devoid of sympathetic treatment. The constant examples of public opinion forcing the State to move in a direction which is apparently against the opinions of the Department in control is irritating and annoying, and the comparison with those examples where there is decentralised control is not favourable to control by the State, hence the preference is much more strongly in favour of State aid as distinct from State control.

Local administration causes competitive activity, one area against its neighbouring area; any progressiveness in one district soon has its effect on the adjoining districts, where the difference in administration is noticeable; a spirit of emulation is aroused and encouraged.

So keen is this competitive or progressive spirit that there are many examples where the improvements and general administration of a particular district so far excels that of another or other authorities that it is quoted as an example to be modelled upon. This would not occur under State control. It is frequently the case, however, that where emulative spirit is low, the roads in particular have been following the old methods and become with increasing traffic worse and worse.

State Aid.--An appeal is made for State aid, and not infrequently this is granted, whereas the other district which has progressed and improved its roads is left, without any assistance, to follow its own methods, which have proved advantageous financially and economically.

If State aid is granted it should be given equally to those areas where the administration is successful and the roads improved, and more in proportion, or a penalty should be imposed on the other authorities, because otherwise it is only an encouragement to the maintenance of a bad system.

Such a system would not be difficult to instal: a scheme could be de-

vised, based on the cost of maintenance of a suitably paved road, the cost of which will be in direct proportion to the amount of traffic passing over the road. Those areas where the maintenance costs are on this basis should receive the highest proportion of State aid; where the costs are higher, with a lower intensity of traffic, the proportion should be lower. An inquiry would discover whether any serious endeavour had been made to lower the cost of maintenance, and where it was so proved, then a grant or loan could be made to execute a larger area by an improved form of construction.

Road Board.—The demand for improved surfaces of roads in Great Britain was so great immediately prior to 1909 that the Development and Road Improvement Act was passed by Parliament in that year and the Road Board was formed. There seems to be little reason why the Act should not be so administered that it should do all that is demanded by the various parties.

The funds available to the Road Board prior to the war were obtained from the tax on petrol and the carriage licences, the income in 1914 being about £1,500,000 per annum. The expenditure by the main road authorities was about £3,000,000

Ordinary Maintenance.—The Road Board[1] takes the view that the local authorities are charged with the maintenance of the public highways, and no assistance can be given towards the cost of ordinary maintenance. Where, however, a work of reconstruction is proposed—even if it only involves tar painting,—the cost of such work is in a proportion met by the Board either by loan or grant.

This position is undoubtedly strong, and in the interests of improved road surfaces, which was the aim of the Development Act.

New Roads, etc.—However willing the Road Board may be to allocate funds for the purpose of reconstruction, the funds are not sufficient to carry out this work on a very extensive scale for all authorities; it is an opinion expressed by many that much more might have been done by the Road Board, because a very large sum has been accumulated, but it seems to have been allocated to some other purpose, apparently to new roads, bye-pass roads, and works of this character.

Road Experiments.—The Road Board has carried out excellent work in providing funds for extensive experimental road structures in various parts of the country in order to test those processes which might prove to be economically effective under moderately heavy traffic.

[1] The Road Board is now abolished, and the duties conferred upon it by the Development and Road Improvement Act, 1909, have been transferred to the Road Department of the Ministry of Transport, which came into existence on 1st October 1919.

As a result of the war, it is probable that either the funds at the disposal of the Board which have been allocated to new thoroughfares will be reconsidered, or new sources of income assured to the Board in order to assist the authorities over the difficulties that have arisen; the roads throughout the country have necessarily been starved in consequence of the shortage of both labour and material, and the traffic has in numerous cases been greatly in excess of the normal for work of a military nature. A large amount of road construction has been carried out during the war by the Road Board for the military authorities.

New Roads and Road Construction.—There are a number of people who think that new arterial roads should be put forward for construction so that the work would provide employment to the men returning from the battlefields. The cost of such proposals is divided into two parts, (1) the purchase of the land and compensation for disturbance, etc., and (2) the construction of the road. With regard to (1), if the land is ripe for development, it might be given up for the purpose of the road, but if it is not ripe and has to be purchased, the cost may be very great and depends on its position. It is not an excessive estimate to say that the cost of reconstruction of 4 miles of road would cost as much as 1 mile of a new thoroughfare.

If this is the case, then it is evident that reconstruction will give more work to labour, will benefit a vastly greater amount of traffic, and will to a considerable extent reduce the cost of maintenance to the local authorities, and will incidentally assist in providing for the inevitable influx of motor traffic which has set in after the war, and the cause of which has already been indicated.

Road Board Policy.—Probably the policy of the Road Board will be modified; it is wholly a question of finance that is the cause of the trouble, and the increased price of materials and labour, which will undoubtedly remain much higher than pre-war rates, will not in any way tend to lighten it. The problem of raising the funds necessary to bring about the reconstruction of roads will be one that will require very careful consideration.

Extraordinary Traffic.—When roads are subjected to a sudden and unforeseen amount of traffic which is of a more or less temporary character, it is possible for the local authority to claim from the person responsible the cost of the damage that this traffic has caused to the roads over which it travelled. In the majority of cases that have occurred the damage is admitted and paid for—in some cases it is not worth pressing, and in a few cases it is disputed. There are cases, for example, where a new reservoir is to be built in a country district, and the cartage of materials to the site is of such volume and weight that the

roads over which it is taken have never been called upon to cater for, and they would not after the works were completed have to cater for anything like this volume or weight. This is clearly a case of extraordinary traffic. So would the case of the removal of the excavations for the tunnels of a railway, as was the case in London; the surplus was taken over some side streets which were never expected to withstand such traffic

One would scarcely expect to find that a business concern that had a quarry from which a few tons of material were carted to various places would be called upon to pay for extraordinary damage merely because they increased their output and employed motor vehicles to deal with it. Yet the Courts seem to have decided that there was extraordinary traffic, and that it must therefore be charged with some proportion of the cost of the damage to the road

The Motor Car (Locomotive) Act definitely prescribes the weight of the load, the diameter of the wheel, and the width of the tire; this being the case, it is only logical to assume that the roads over which these vehicles travel must be made of such material that they will withstand these vehicles. Then, provided that the vehicles conform to the regulations, there should be no claim for extraordinary traffic, except in the cases similar to those described above.

CHAPTER II.

MACADAM ROADS.

Macadam.—This type of road is so common all over the country and in foreign countries that it will be difficult for many who have become so accustomed to it to realise that this form of construction is one of the most unsatisfactory from almost every point of view. It has been thought that the road is cheap to construct and not expensive to maintain, and the fact that it has been allowed to continue is due to the fact that the expense of maintenance is an insidious growth. It is only two years ago that the writer came across several cases where the cost of maintenance was estimated at from 1s. 6d. per superficial yard per annum to 2s. 4d. per superficial yard per annum. The suggestion that whenever a macadam road cost 1s. per square yard per annum to maintain it should be dispensed with and asphalt or wood paving substituted, because it was cheaper and more satisfactory, was regarded with incredulity. This, however, is becoming more and more recognised as the right view, and macadam roads are being considered as an antiquated form of pavement which should be replaced with paving more scientifically constructed.

The International Road Congress naturally considered this form of construction in all its bearings, and a resolution was passed unanimously and without discussion as follows :—

"Macadam carried out according to the methods of Tresaguet and Macadam causes mud and dust, is expensive to maintain, and is suitable in large cities only for streets where the traffic is not very great or heavy."

Having regard to such a condemnation of a road structure that has been the vogue for so many years, and which has received such attention from road engineers throughout the world, it is excusable if, in a work dealing with modern road construction, this form of structure is dealt with in a manner which may be said to emphasise the defects and tend

to hasten its abolition or substitution for a structure more in accord with the requirements of the public.

The writer considers that even for streets with light traffic a cheaper and better form of construction can be adopted, and that there are few instances indeed where the macadam road need be installed.

The method of constructing a water-bound macadam road is so well known, and so fully described in many other volumes, that it would seem superfluous to deal with it here. It is necessary, however, to do so, as there are a number of details in the construction from which valuable inferences may be drawn.

"Macadam" is a name that has been given to stones of granite, basalt, limestone, flint, etc., broken for road purposes to a size of about 1½, 2, 2½, or 3 inches. The word is derived from John Loudon Macadam, an engineer who, in the early part of the nineteenth century, conceived the principle that if stones were broken to a size of 2½ or 3 inches, and placed on a road to a depth of from 6 to 8 inches, they would wedge themselves together and form a good road surface.

Tresaguet.—Previous to Macadam was Tresaguet, a French engineer, who advocated a foundation of rough stones, gradually lessening their size to small material.

Telford, later than either of these engineers, divided the road into two parts, the *foundation* and the *surface structure*. The foundation was composed of large rough stones placed by hand in the excavated ground, and the crevices left in the surface of these rough stones were packed and filled with smaller material. He then placed on the top of this foundation Macadam's sized stones, and added a surface layer or coating of gravel about 1½ inches thick.

Telford Foundation.—This type of foundation is known as the "Telford foundation," and it is accepted as the most satisfactory form which has been devised, except concrete.

Present-day Macadam Road.—The surface construction of the present-day road is not the same as that of either Macadam or Telford. The size of stones is about 2 inches; that is, they are so broken that they will pass through a 2-inch ring, and they are laid in two 4-inch layers, which are each rolled to 3 inches; the interstices are filled with granite chippings, with fine material of a somewhat loamy character, or they may be filled in with gravel or hoggin, in which loamy material is naturally placed. Thus the total depth of macadam is 6 inches.

This is termed a *macadam road*, although the construction differs materially from Macadam's methods, and more nearly approaches to Telford's ideas.

A sketch of the Telford foundation and the modern macadam road is given in fig. 8.

Although Telford's foundation is accepted as a model, it is only adopted where the material can be suitably and cheaply obtained. There are many miles of roads which have not such a foundation. In many cases it will be found to be composed of the hard clinker from the destructor furnaces; in other cases the broken bricks from buildings that have been pulled down are used as "hardcore."

Modification of Telford Foundation.—In such instances there is some variation from the above-described methods. The road is excavated to a depth of 18 inches below the finished surface, and, if the nature of the subsoil is of a loamy character, is filled with about 18 inches of clinker refuse in large pieces or hardcore (not less than 5 or 6 inches), and is subsequently rolled with a steam-roller weighing about 12 tons, until the hardcore is 6 inches below the finished surface. If after continuous rolling the subsoil will absorb more material, this is added until no further depression is evident. On this foundation the two layers of macadam described in a previous paragraph are laid.

Settlement of Modern Macadam Road.—The surface of a macadam road newly laid does not maintain itself, as traffic forces the stones out, and thus loosens the surface. If, however, the road is carefully watched and allowed to properly dry out before the traffic comes upon it, and if the traffic that is allowed to come upon it subsequently is fairly heavy and continuous, the surface will more satisfactorily keep its position. Where the traffic is occasional, the surface is not maintained, and it becomes necessary to occasionally re-roll to force the stone into position.

Effect of Hardness of Stone.—The harder the granite, and the harder the stone and fine stuff that composes the matrix, the more difficult does it become to obtain a permanent surface. The softer the stone (*e.g.* limestone), the more easily crushed it is, and a good surface is more quickly secured.

The writer is of the opinion that the rolling on the macadam causes a grinding between the stones from which a cementing dust or fine impalpable powder is evolved. As the roller does not continue at work long enough to make sufficient fine material, the stones are easily displaced, but subsequent heavy traffic increases the grinding and more fine material is formed. If a man watched the road and carefully replaced any dislodged stone, after a few days there would be little necessity for the steam-roller to perform any "back rolling." Such rolling is scarcely necessary on roads formed with limestone, because of the fine dust that is readily formed by the action of the roller on the stone when

the latter is plentifully supplied with water. In other words, the work done by a roller on the new road is equal to several months' wear.

Cementing Power of Dust Powder.—It is well known that almost any material if ground to an impalpable powder, with moisture and under pressure, will form into a mass. For instance, flints will not adhere if they are ½ inch, 1 inch, or 2 inches in size, but if the stone is further broken to very fine particles the sand will, with moisture and under pressure, become somewhat solid. An example of this may be seen by the considerable depth that can be dug on the seashore without support, or in pits where sand will retain a vertical face for a considerable time. If this sand could be ground still finer, no doubt its cohesive properties would be proportionately greater ; if, however, the moisture is in excess, the mass will not adhere.

Granite is composed of a number of oxides of silicon, potassium, iron, magnesium, etc. ; these materials may, when in a finely ground state with moisture, react chemically and form a binding agent of more or less power, and the cementing result that is desired is attained. A loamy or ferruginous hoggin is frequently added to the fine material so that combination may more quickly take place. Whatever the actual process going on, it is almost certain that this fine impalpable powder is essential to keep the stones in position to form a good surface in a water-bound road. It is equally clear that this grinding is continuous with the traffic, as there is quite 100 per cent. more fine material in a road that is worn out than was originally placed there.

New Road Composition.—A newly made road is composed of granite and hoggin in somewhat the following proportions :—

Granite	55 to 60 per cent.
Hoggin	25 ,, 35 ,,
Moisture	5 ,, 10 ,,

A road that is in excellent condition is composed in the following proportions :—

Granite	About 55 per cent.
Fine material	,, 45 ,,
Moisture	,, 5 ,,

A road that is worn out and requires repair has the following proportions :—

Granite	40 to 45 per cent.
Fine material	45 ,, 50 ,,
Moisture	5 ,, 10 ,,

Effect of Moisture.—The above figures will show how it is that an

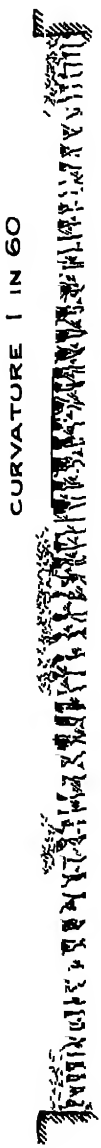


FIG 8.

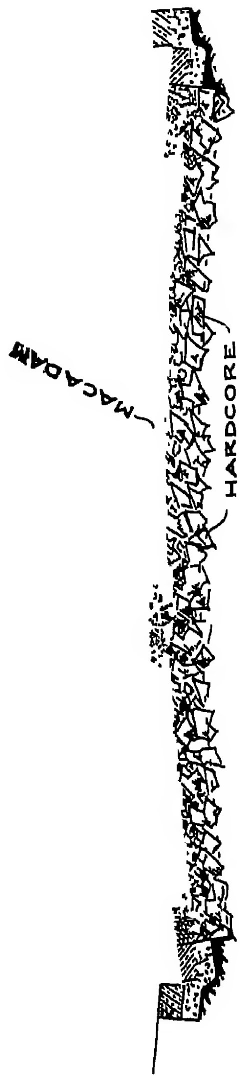


FIG. 9.

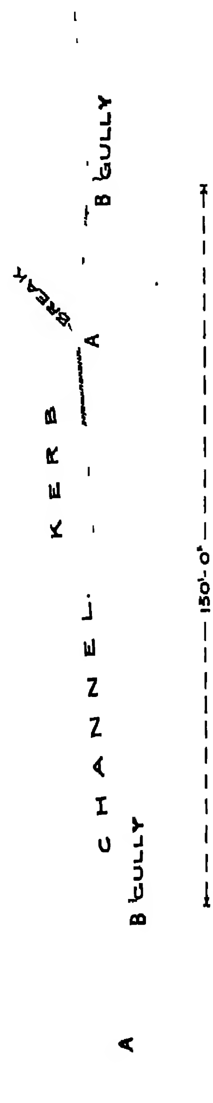


FIG. 10.

old road is more muddy than a new road in wet weather. In such circumstances there is an excess of moisture which acts as a lubricant, the large stones being forced downwards through the fine material, which comes

up to the surface. If this fine material is not removed, the moisture will evaporate in dry weather, and the traffic will compress the mud into a compact and solid mass again. Thus the surface becomes smooth and even, showing the cementing properties of the impalpable powder.

Another phase to be noticed in the action of moisture in excess is that if material of different specific gravities are in the composition, the material which has the lowest specific gravity will come to the surface and remain there, while that of higher specific gravity will sink or assume a lower position. It is therefore essential that the materials composing a road surface should be as nearly as possible of the same specific gravity. If, however, there should be a material of low specific gravity, it should be so placed in the structure as not to be easily moved from its position.

It is interesting in this connection to note that if a quantity of large material is placed with a quantity of fine material in a box and vigorously shaken for some time, the large material will find its way to the surface; but if pressure is applied the fine material is forced upwards.

Drainage of Roads.—From the foregoing it will be quite apparent that an excess of water on a road surface and in its structure is detrimental, and therefore any rainfall should be immediately dealt with. The contour of the surface should be so designed that the water may pass as quickly as possible to the channel, and the channel should be so graded that the water shall pass equally quickly to the gully. The macadam surface is not so regular as other surfaces, and in order to obtain these results the fall from the centre of the road to the sides is greater than for any other form of road surface.

These roads, as a rule, have an average fall from the centre to the sides of 1 in 20, but this figure is not constant.

On a *level road*, or one with a slight grade, the channels must have a fall of 1 in 150 to 1 in 180, the gullies being placed 150 to 180 feet apart, the nearer the better, in order to more quickly remove the water from the road. It will be evident that the contour, if 1 in 20 at the apex of the gully drainage area or break of the road, will be much greater at the gully itself (see A and B in fig. 10).

When, however, the *grade* is a steep one, that is, greater than 1 in 50, there is no necessity for a fall of 1 in 20 from the centre to the side. In fig. 11, which is a half plan of a road, A B is the centre line of the road, D C G is the channel, half the centre third A E of the road has a fall of 1 in 144, and the remainder has a fall of 1 in 37, this being calculated the fall of a barrel-shaped contour. Suppose that the road has a longitudinal fall of 1 in 50, both in the centre of the road and in the channel, it will be seen that if lines are drawn from A at 30°, 45°, 60°, etc., the water will

take a course in the direction of A C, *i.e.* at an angle somewhat less than 45° from the centre line of the road. Thus the fall from the centre of the road to the side might be greatly reduced.

The centre third of the road is shown to have a fall of 1 in 144, and as the direction of the water will be in the direction of A C, it would therefore seem that if a road has a longitudinal fall of anything greater than 1 in 100, the contour, without detriment to its capacity for throwing the water off its surface, can be modified in the direction suggested, *i e.* instead of making the road "barrel-shaped," the curve of the centre third should be continued regularly to the side, as shown in fig. 6 by the dotted line.

Kinds of Road-building Stones.—The material forming the surface of the modern macadam road is generally of granite, which is a

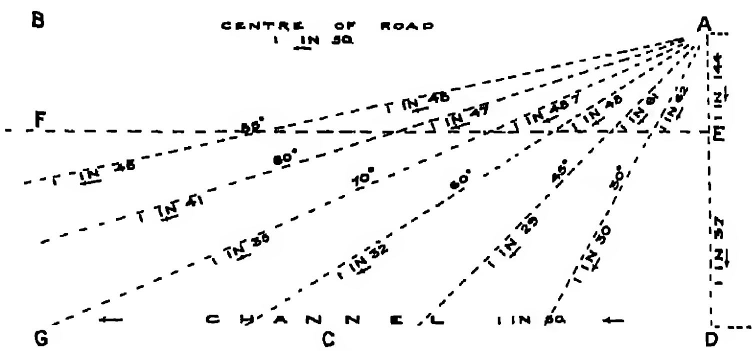


FIG. 11.

technical but also a popular name for all plutonic rocks used as macadam, and equally applies to syenites, diorites, andesites, diabases, gabbros, etc.

In many parts of the country these rocks are not available, and the freight charges from the quarries make the stone too expensive. Local authorities have therefore had to fall back on the next hardest material available—which is usually limestone, ragstone, or flint, etc.; each is used in precisely the same way as granite. Limestone and ragstone make a very white road, very dusty in the summer and muddy in the wet wintry weather. Flint probably gives throughout the year a clean and most pleasant appearance, *i.e.* a reddish-brown surface; but the stone easily breaks up to fine grit and wears very rapidly.

Iron and steel slag are used in large quantities in the Midlands and in some parts of the North of England, where it is locally available. The road so formed makes a very muddy surface under traffic in wet weather.

Guernsey granite finds more favour in the South of England than any other stone, on account of its good wearing qualities.

In the Midlands, the granite from Clee Hill and Leicestershire similarly finds a more ready market, while in Lancashire and Yorkshire the Penmaenmawr granite is extensively employed in road construction.

In Scotland, where granite of various qualities is obtainable, the local stone is used, and this is also the case in Ireland.

Size of Stone.—The custom, then, is to use the locally obtainable stone and not to consider too closely whether it is better or worse than outside material, although this is kept in view. The difference in the cost of the various stones is always an important factor, and although one may be harder and have better wearing qualities, the manner in which it is broken will quickly nullify all its other advantages. Stones should be broken as nearly as possible to a cubical shape in order to obtain the best results, but there are many stones that have been sent from the quarries so broken that although they may have been just able to pass a 2-inch ring in one direction, in the other direction they would easily pass 1-inch.

These shell-like stones are easily broken under traffic conditions, and the stone is frequently on that account disparaged.

Attrition Test.—Probably the best test for obtaining an accurate idea of the wearing qualities of the stone under the best conditions is the attrition test.

It is carried out by means of a rotary cylinder 11½ inches diameter, in the inside of which is placed three ribs 1 inch × 1 inch. Four lbs. of broken stone 1½ inch diameter are placed inside this cylinder, which is revolved at the rate of 20 revolutions to the minute, until 8000 revolutions have been made; the stone is then removed, and the total weight of any chippings retained on ⅛-inch sieve, and of all dust in the cylinder and on the stone, is found and its percentage of the original weight determined. Similar tests may be made of 2-inch stone, and also under wet conditions; the latter is carried out in a similar manner to the dry test, but ½ gallon of water is added.

The following percentages for the stones mentioned on previous pages will show the relationship of the various granites—they are taken from the tables which were made by Mr Lovegrove, M.Inst.C.E., the borough engineer of Hornsey; the machine used was that designed by the late Mr T. de Courcy Meade, M.Inst.C.E., city engineer of Manchester:—

TABLE VII.

Material.	Chips. Dry.	Chips. Wet.	Dust. Dry.	Dust. Wet.	Average.	Specific Gravity.
Guernsey granite 1½ ins	0·44	·05	6 78	10·40	8·59	2 86
Guernsey granite 2 ,,	1·76	05	6·15	9·91	8·03	2·86
Quenast granite (Belgium)	0·00	0·00	2 93	4·54	3·73	2·76
Clee Hill granite . .	0·00	0 00	6 00	8 45	7·22	2 91
Penmaenmawr granite .	0·00	0 14	2 44	3 76	3·10	2 73
Flints	2·34	2·73	11 82	9 08	10·45	2 63
Slag	0·00	1·32	8·20	14·40	11·30	3·02
Limestone	1·85	3·95	17·53	30·71	24·12	2·71

The chips and dust made in this machine are merely examples of what will happen under similar conditions, and it is suggested that, even if the conditions do not apply in a road, the relationship of the dust-making qualities of the various stones is established.

Effect if properly embedded.—If, however, these stones can be embedded in a mortar or matrix which will prevent movement and reduce the grinding to a negligible quantity, then in this respect the test has no value, because one class of stone would have equal value with another.

Toughness.—A piece of stone is taken and made cylindrical, 3 inches long and 1 inch diameter, and the test made with a hammer on the principle of a pile-driver; the weight of the hammer is 2 kg.; the fall is 1 cm. for the first blow, 2 cm. for the second, and so on until the failure of the test-piece occurs. The number of blows is the toughness.

Cementing Value.—A kilogramme of the stone is broken to pass through a 6-mm. screen, but not so small as to pass through a 1-mm. screen. It is then moistened with water and placed in an iron ball mill containing two chilled iron balls weighing 25 lbs. each and revolved at a rate of 2000 revolutions per hour for 2½ hours, or until the material has been reduced to a thick dough, the particles being reduced to 0 5 mm. About 25 grm. of this material is then placed in a cylindrical metal die 25 mm. in diameter, and by means of a hydraulic press is submitted to a pressure of 100 kg. per square centimetre. Five of these briquettes are taken out and allowed 12 hours in air and 12 hours in a hot oven at 100° C. After cooling in a desiccator, they are tested by impact in a machine similar to that described under the head of toughness, except that the weight of the hammer is 1 kg. and the drop does not exceed 10 cm.

The standard fall of the hammer is 1 cm., and the average number of blows required to destroy the bond is the cementing value.

Hardness or Coefficient of Wear.—Hardness is the resistance which the stone offers to the displacement of its particles by friction, and varies inversely as the loss in weight by grinding with a standard abrasive agent.

The test-piece is a cylinder 3 inches × 1 inch diameter, and placed in a grinding machine in such a manner that the base of the cylinder rests on the upper surface of a circular grinding disc of cast iron which is rotated horizontally by a crank movement. The specimen is weighted so as to exert a pressure of 250 grm. per square centimetre against the disc, which is fed from a funnel with sand of about 1½ mm. diameter. After 1000 revolutions the loss in weight of the sample is determined, and the coefficiency of wear obtained by deducting one-third of this loss from 20.

Comparison with Concrete.—In *concrete* where broken bricks, clinker refuse, and other kinds of somewhat hard material are used as the aggregate, abrasion tests would be of no service; the aggregate in this case takes a secondary place, and the cement takes the premier position and is severely tested before use. The cement and sand forms the matrix of the concrete, and it will be the matrix of the bituminous macadam which will be of the first importance in road construction. The aggregate will be of secondary consideration, and will have to come into line with the matrix; and if the stone is too hard, a softer material will have to be tried.

The stone will become exposed to the beating of horses' feet and the friction of the driving wheels of a motor vehicle. Some test will probably have to made or designed to test the capacity of the stone to resist this form of treatment.

It is, however, undoubtedly the case that these attrition tests have been of great service in assisting engineers to make their choice of a material which would improve the water-bound methods of construction, but they give no criterion of the life of a pavement; otherwise pieces of wood similar to that used in wood paving, if placed in the machine, would probably show no attrition. It is recognised that wood paving lasts longer than any of the best granites in a macadam road, and so the test is applicable only to water-bound macadam roads.

CHAPTER III.

WEAR OF ROADS.

Wear on Macadam Roads.—In the year 1831 a Select Committee was appointed to inquire into the effect of steam-propelled vehicles on public highways Sir (then Mr) John Macneill gave evidence, which was to the effect that the wear on the roads was, in his opinion, due to the extent of from 60 to 80 per cent. to the traffic, and from 20 per cent. to the weather; 20 per cent. to coach wheels, and 60 per cent. to horses' feet; and where waggons are employed, 20 per cent. to the weather, 35·5 per cent. to waggon wheels, and 44·5 to horses' feet.

It is only within the last two or three years that an example practically confirmed these conclusions. A road A had been accustomed to a certain amount of traffic which was tabulated. Another road B was to be closed for repairs or improvements, and the traffic that had been in the habit of traversing the road B was for some months to be transferred to road A (the traffic of road B had also been noted). The cost of the repair of A under normal conditions was compared with the repair under the extraordinary conditions, and the difference was not found to be proportionate to the increase of traffic, but there was an increase which was put down to weather conditions, the results being very similar to those obtained for the above-mentioned Committee.

Wear due to Traffic.—In other instances the wear is almost wholly due to the traffic; one might easily be led to consider that a mistake had been made if the wear due to the weather was made to be much larger than the wear due to the traffic, although it is possible that at the time the conditions were all in favour of such a conclusion. Probably, if a critical examination had been made at the time, a different result would have been obtained, which would have caused the methods of construction to be seriously amended, if not abandoned.

Wear on Frost-bound Road.—The illustration that brought the subject into question was the manner in which a traction engine had been stuck deep in a field but easily got out when the moist earth became frost-

bound. It was also noticed that a very weak road easily withstood the traffic satisfactorily under frost conditions. If the road A had been frost-bound during the time the traffic from road B had been traversing it, the wear would have been no more, if as much, as the amount that had been the case without B's traffic.

Wear on Moist Road.—If a water-bound road is in a very moist condition it would be quite unable to withstand heavy or light continuous traffic for very long. Consequently, it is not the traffic, *per se*, but rather traffic in combination with certain unfavourable weather conditions.

Division of Wear.—Wear due to the weather, without traffic, would be an exceedingly small item; traffic wear on granite is also a small item, as is evidenced by the long-lasting properties of granite setts in a paved road. Macadam roads are mainly composed of granite and other material equally hard in itself, so that wear on a water-bound macadam road may be divided into three sections:—

1. Surface wear due to the traffic;
2. Surface wear due to the weather; and
3. Interior wear due to the weather and intensified by the traffic.

If the wear under section 1 is small, and under 2 and 3 is large, then if any means can be applied to eliminate the weather effects in these sections, the cost of road construction must be considerably decreased: in order to gain some idea of the proportions to be allocated to each section, it is advisable to consider the actual wear on other classes of pavement.

Comparison of Wood Paving, Asphalt, and Macadam. One of the most satisfactory forms of pavement is that of soft wood. The fibre of a red or yellow deal may not be considered at first sight to be as well able to resist traffic wear as granite; similarly, asphalt would not be considered from its structural appearance to have as good a wearing face as granite. As a matter of fact, this conclusion would be a perfectly legitimate one if the granite could be laid down in a sheet from side to side; however, granite is not so used, as it would be too slippery, but is broken up into macadam, and it is remarkable how in this form the granite loses its superiority, and the wood paving and the asphalt prove more satisfactory in every way.

It is obviously the case, therefore, that the stone is not at fault, but he structure or method of adaptation.

Comparison of Wood, Asphalt, and Macadam.—For comparison purposes, a good class macadam road, properly constructed, with a good foundation and with a certain amount of heavy traffic, lasts about two

years. The same road, with the same traffic, if laid with concrete foundation and 2-inch layer of rock asphalt, would remain with an even surface for probably twenty years. Similarly, the same road, if laid with soft wood paving, would wear satisfactorily for quite fifteen years, and at the end of the periods there would be a mass of asphalt or wood which could be re-used. The asphalt need only be remelted and treated again, and the wood blocks could be cleaned and used for repair purposes. The writer has taken out all blocks 3 inches and over in thickness which have been in a road over fifteen years and re-used them in roads under heavy traffic, and in some cases they have been down five or six years. After this road had been repaved the same blocks have been cleaned and sorted and used for repairs again.

Effect of very Dry Weather and of very Wet Weather.—An examination of a macadam road on a dry windy day will discover a large amount of grit in the channels and occasionally on the footpath.

Similarly, on a wet day, with continuous heavy rain, the channels will be covered with a thick coat of fine muddy grit. The road may or may not have had much traffic upon it. If the traffic has been heavy the road is in a heavy clogged condition, and the mud is either in a condition for being easily swept by a scavenging gang, or a heavy rain will still further wash this material to the channel. Five or six years ago these conditions were observed, and an examination of the records of the tonnage swept on a wet day showed that the weight was two and three times greater than in the case of the amount swept up on a dry day. The moisture in the mass would not account for the whole of the difference; it was obvious that the weather had brought up from the interior of the road a considerable quantity of gritty material.

At the International Road Congress in London, 1913, there were a large of number of papers submitted and discussions took place on the gist of opinions expressed in those papers In a large measure the resolutions that were approved were of a very general character, as is natural, seeing that there are no two countries in the world where the conditions are exactly similar. In the British Isles we have a moist atmosphere all the year round; in other more extensive countries the atmosphere is either dry or much less moist Then, as regards the weather, it is in this country somewhat as was described by an American commercial traveller who, when he returned to the United States, was asked what he thought of the weather here, replied: "Very good as samples"—from which one might infer that when a rain occurred in America there was a continuous downfall, or if a frost it would last a considerable time, and so on, whereas here we may have rain, frost, and snow on the same day. Such weather has a very bad effect on pavements,

and special precautions have to be taken which would not be necessary to the same extent elsewhere On the other hand, the range of temperature here is within more reasonable limits, and would be easier to cater for than in those cases where the range was much greater, or on a higher or lower scale.

Conclusions at International Road Congress on Weather.—From the Resolutions passed by the International Road Congress, the following are extracted :—

"1. Weather conditions are amongst the most powerful influences which cause deterioration of roads, and that the destructive effects of weather can be minimised by effective waterproofing of the road surface, with suitable drainage for the foundation.

"2. Any considerable volume of traffic, consisting of either heavy vehicles or high-speed light motor cars, has a seriously damaging effect on water-bound macadam roads. The damage caused is effected by the balancing of the motor, the ratio between propelling power and adhesive weight ; the weight of unsprung portions of the motor, the progressivity of action of the brakes, the system of springing, the type of tires employed, the diameter of the wheels, the width of the rims, variation of speed, and adhesion and other factors.

"3. The damaging effect of heavy motor vehicles can be minimised by the use of wheels of large diameter ; tires of a width properly adapted to the weight of the axle load ; rubber or elastic tires and suitable springs, and that all reasonable means of reducing the damage to roads caused by such vehicles should be enforced.

"4. Except in the case of sharp curves, light motor-car traffic does not cause serious or exceptional wear or damage to properly made macadam roads which have been treated or bound with tarry bituminous or asphaltic materials.

"As regards horse-drawn vehicles, it is also desirable to study the relations between load, width of rims and diameter of wheels, and more especially the shoeing of horses. It is also necessary that power should be given to local authorities to prevent the deposit of refuse from the fields and earth upon the roadway by the wheels of agricultural carts.

"5. There is a great lack of precise information in regard to the various causes of wear and deterioration of roadways, and that it is desirable to collect more information compiled on carefully devised scientific methods standardised as far as possible for the purpose of comparison, and to make further systematic study of these causes.

"The International Permanent Commission is charged with the preparation of a programme of observations, studies, and experiments."

Comments on these Conclusions.—These resolutions are based in

a very large measure on the effect that the traffic has upon roads which are unsuited to the traffic now coming upon them, whereas in pre-motor times these roads did not so easily become damaged, owing mainly to the fact that the traffic was not so great either in speed or weight; for example, the effects are seen on macadam roads clearly, but they are less clear on both asphalt and wood paving, and scarcely noticeable on granite setts. It would be difficult to say that speed has a deleterious effect on a road pavement, when on a good road the tractive effort of a vehicle travelling at high speed is only about 35 to 40 lbs. per ton, whereas the effort for low speeds is about 19 lbs. per ton.

The Satisfactory Road Structure.—The secret of the satisfactory road structure is wholly contained in the "maintenance of an even and regular surface"; the difficulty is to obtain a structure that will give this surface and at the same time be reasonable in cost, *e.g.* a road made of rustless steel would have an indefinite life, and none of the observations put forward in the above resolutions would apply, because the causes of damage there mentioned would not affect such a surface; but the cost of such a road structure would be so great that no authority could afford to lay it down. To go to another extreme, one could probably secure an almost pure rubber pavement, but the same argument applies as to its cost; the two examples of rubber pavement coming within the knowledge of the writer cost about £5 per superficial yard, whereas local authorities are demanding road structures at a cost of from 2s. to 5s. per superficial yard. There is a wide difference between these figures.

The Best Substitute.—Instead of accepting the ideal material, road engineers are endeavouring to secure something which is probably at best a cheap substitute, and because it is difficult to make the substitute do as much as the ideal, available but expensive material, owners of vehicles are being asked to assist by suiting their vehicles to conditions required by the substitute. This is a perfectly reasonable attitude, because in any case the user has to pay a proportion of the cost, and he ought therefore to be willing to assist as far as possible.

But the question arises as to whether any material alteration is possible. It has not been decided which of the two damaging factors is the more deadly—weather or traffic. The writer is strongly of the opinion that the weather has by far the most damaging effect on macadam, and to a small extent on asphaltic pavements; it has least effect on wood paving and granite setts, and would have little effect on the iron or rubber pavements mentioned above.

Weather and Traffic.—It has already been mentioned that weather effects are trifling if there is no traffic. This must be obvious, but the

point that is intended to be raised is that the weather has some definite effect on the pavement, so that when the wheel comes into contact with the area so affected the road structure is thereby damaged, probably by the weight of the load on the wheel, the speed, or a combination of both. Damage that is so caused brings about unevenness at that point; and once unevenness makes itself apparent and is not remedied, the vehicle, by means of the transference of the shock due to the use of springs, causes excessive or alternating extra effects, *i.e.* an excess of the usual weight and speed effect on the neighbouring area over which the wheel has to traverse. Thus these adjoining areas become affected, and eventually it is spread over the whole length of the pavement. This is demonstrated on the diagram (p. 96), and the deduction is that the traffic is only a subsidiary cause; the real cause is, as will be gathered, the effect of the weather on the material composing the structure.

INVESTIGATIONS ON THE WEAR OF WOOD PAVING.

In order to investigate the matter still further and to endeavour to discover the proportion of wear due to the traffic and to the weather, the rate of wear was taken of the wood-paved roads; it will be gathered that there would be no internal wear of wood pavements, it would be wholly surface wear due to tractional resistance. Table VIII. gives the results for the year 1914–15, and included in the table is the wear of the pavement averaged over a period of three years prior to 1914. The date when the pavement was laid down is also indicated, its life in the year 1918, and the estimated life of the pavement based on the rate of wear divided into the depth of 2·00 inches, which is the limit of wear allowed.

It will be noticed that in several cases there are roads in which wood pavement has been laid and the actual life exceeds the estimated life of twenty years. The life of a pavement is limited so far as the calculations are concerned to twenty years, even if the figures permit of a longer term.

Depth of Block according to Volume of Traffic.—It is also clear that in several instances it would have been equally satisfactory and less costly if the blocks had been 4 inches or even 3½ inches deep. It might even be more advantageous to lay the shallower blocks in main thoroughfares, as after a period of nine or ten years there are weak places in the pavement due to inequalities of the timber, which are developed by heavy traffic, and cause more frequent repairs to secure the even surface and use to the full the blocks in the remainder of the pavement.

TABLE VIII.—WOOD PAVING.

Name of Road	Area in Superficial Yards.	Previous Life.	Year when laid.	Life in 1918	Original Depth	Depth in 1914	Total Wear	Rate of Wear per annum	Average of last Three Years	Estimated Life.	Remarks.
		Yrs.		Yrs	Ins.			In	In	Yrs.	
1. Avonmore Road .	6,220	.	1900	18	5	3 80	1 14	0 08	0·080	20	
2 Baronscourt Road .	618	.	1900	18	5	4 39	0 61	0·04	0 018	20†	
3 Carnwath Road . .	005	.	1902	16	3	2 07	0 83	0 02	0·02	.	Dowelled Jarrah asphalt substituted in 1918. Contraction very bad.
4 Dawes Road—											
Farm Lane to Salisbury	6,170	13 7	1905	13	5	4 10	0 60	0·07	0 070	20	
Salisbury to No. 105	1,538	..	1890	22	5		.	.	..	..	A large area repaired in 1918
No 105 to Munster Road	2,800	13 1	1909	9	5	4 72	0 28	0 05	0 06	20	
Munster Road to Police Station	2,540	16 0	1912	6	4½	4 38	0 17	.	..	.	* Laid with red gum which was unsatisfactory.
5. Distillery Lane .	1,050		1901	17	5	4 78	0 21	0 01	0 018	20†	
6 Farm Lane . .	1,081	.	1900	9	4	3 78	0 22	0 04	.	20†	† The estimated life, although it may exceed 20 years, is taken at that figure.
7 Fulham Road—											
Stamford Bridge to No. 525	4,810	11	1904	14	5	3 76	1·24	0 12	0·12	18	
No. 525 to Cedar Rd	1,154	18 1	1911	7	5	4 84	0 16	0 05	.	20	
Cedar Rd. to Fire Stn.	7,200	{ 12 / 2* }	1904	11	5	3 89	1 11	0 11	0 12	18	‡ These areas were repaved with old cleaned blocks.
Fire Stn to Epple Rd	2,800	13 7	1904	14	5	4 18	0 82	0 08	0 08	20	
Epple Rd. to Burlington Rd.	9,300	15	1905	13	5	4 38	0 67	0 07	0 088	20	
8. Fulham High Street and Putney Bridge Approach—											
Burlington Road to Church Row	4,040	14·0	1907‡	11	5	4·46	0 54	0·08	0 080	20	
Church Row to sett paving, Putney Bridge	2,708	14 0	1909‡	9	5	4·41	0 59	0 10	0·106	20	
9. Fulham Palace Rd.—											Tramways were laid through these roads in 1908.
King's Head to Bishop's Avenue	3,430	9 1	1908	10	5	4 74	0 20	0 04	0 046	20	The tramway area is 14,418 superficial yards.
Bishop's Avenue to Gowan Avenue	2,802	.	1809	10	5	4 41	0 59	0 04	0 048	20	
Gowan Avenue to Inglethorpe Street	5,145		1901	17	5	4 32	0 68	0 05	0·058	20	
Inglethorpe Street to Crabtree Lane	6,788		1908	10	5	4 79	0·21	0 04	0 04	20	
Crabtree Lane to borough boundary	9,388	..	1809	10	5	Extensively repaired.					
10. Harwood Road—											
Fulham Road to Town Hall	510	15	1907	11	5	4 45	0 55	0 08	0 09	20	
Town Hall to New King's Road	4,624	10	1908	10	5	4 61	0 39	0 07	0 060	10	
11. Hurlingham Road .	500	.	1908	10	5	4 79	0 21	0 03	0 033	20	
12. Jerdan Place . .	542	{ 9 0 / 9 6 }	1910	8	5	4·76	0 24	0 07	0·07	20	
13. King's Road—											
Stamford Street to Britannia Road	2,680	{ 8 1 / 11.4 }	1907	11	5	4·24	0 76	0 11	0·106	20	
14. New King's Road—											
Britannia Road to Bagley's Lane	1,958	11·1	1907	11	5	4·27	0 73	0·10	0 093	20	4-in. recommended instead of 5 in.
Bagley's Lane to Wandsworth Bridge Road	1,154	16·10	1912	6	4·5	4 41	0 09	.	..	..	do.
Wandsworth Bridge Road to Broomhouse Road	10,702	..	1898	20	5	3 82	1 18	0 07	0 07	20	do.
Broomhouse Road to Ashington Road	1,715	..	1894	24	5	A considerable area repaired.					do.

TABLE VIII.—*continued.*

Name of Road.	Area in Superficial Yards.	Previous Life.	Year when laid.	Life in 1913.	Original Depth.	Depth in 1914.	Total Wear.	Rate of Wear per annum	Average of last Three Years.	Estimated Life	Remarks
14. New King's Road—*cont*		Yrs		Yrs	Ins.	Ins.	Ins.	In.	In	Yrs	
Ashington Road to Burlington Road	3,576	.	1800	10	5	3·77	1·23	0 08	0·083	20	4-in. instead of 5-in. blocks recommended in this case.
Burlington Road to High Street	2,000	..		.	6	4 00	Largely patched.				Pitch-pine blocks.
15. Lillie Road—											
Fulham Palace Road to Police Station	2,032	13·7	1000	12	5	4·38	0 62	0·08	0·00	20	
Fulham Cross to North End Road	8,980	.	1807	21	5	3·61	1·39	0·08	0 083	20	
North End Road to Richmond Place	4,407	0 10	1007	11	5	4·33	0·67	0 09	0·10	20	
Lillie Bridge, Richmond Place, to boundary	764	11·4 10 8 0·8	1008	10	5	4·16	0 84	0 11	0 16	18	
16. Margravine Road—											
Greyhound Road to Gastein Road	230	..	1002	16	5	4 23	0·77	0 06	0·06	20	4-in. recommended.
17. May Street and Greyhound Road—											
North End Road to Fulham Palace Rd.	12,300	.	1000	18	5	4·18	0·82	0·06	0 06	20	do.
18. Moore Park Road—											
Harwood Road to Waterford Road	940	..	1891	27	5	4 27	0 73	0 03	0·03	20	do
Waterford Road to Fulham Road	2,970	..	1008	10	5	4 80	0·20	0 03	0·033	20	do.
19. Munster Road—											
New King's Road to Fulham Road	8,180	.	1005	18	5	4 70	0 30	0·03	0·030	20	do.
Fulham Road to Dawes Road	9,456	.	1900	12	5	4·75	0 25	0 03	0·030	20	do
20. North End Road—											
Matheson Road to Star Road	8,000	0 2	1898	20	5	3 24	1 76	0·11	0·11	20	
Star Road to Seddlescombe Road	3,400	11·0 1 10	1904	14	5	3 67	1·33	0·12	0·120	17	
Seddlescombe Road to Walham Gn. Convenience	4,230	10 3	1007	11	5	4·40	0·60	0 08	0·09	20	
Walham Gn Convenience to Dawes Road	1,907	13·11	1010	8	5	4 80	0·20	0·05	..	..	
Dawes Road to Fulham Road	1,907	..	1806	22	5	3 53	1·47	0 08	0·08	20	
21. Rylston Road .	670	.	1902	10	5	4·35	0·65	0·05	0·05	20	4-in. recommended.
22. Sherbrooke Road .	2,111	..	1893	25	5	3·83	1·17	0·05	0·058	20	do.
23. Stamford Street .	400	..	1905	13	5						
24. Stanley Bridge—											
Centre to Stamford Street	872	8·1 9·8 8·1	1913	5							
25 St Dunstan's Road—											
Fulham Palace Road to Margravine	2,050	..	1905	13	5	4·70	0·30	0·03	0·033	20	do.
26 Vanston Place—											
Fulham Road to Farm Lane	1,121	13·7	1910	8	5	4·77	0·23	0 06			
Farm Lane to North End Road	540	..	1892	26	5	3·46	1·54	0·07	0·066	20	do.
27. Wandsworth Bridge Road—											
New King's Road to Sandilands Road	5,007	..	1895	23	4 & 4½	Centre area relaid only, 1013 sup. yards					
Hazlebury Road to Oakbury Road	2,380	..	1898	20	5	3 38	1 62	0·10	0·10	20	

TABLE VIII.—*continued.*

Name of Road.	Area in Superficial Yards.	Previous Life.	Year when laid.	Life in 1913	Original Depth.	Depth in 1914	Total Wear	Rate of Wear per annum	Average of last Three Years.	Estimated Life.	Remarks.
37. Wandsworth Bridge Road—*cont.*				Yrs.	Ins	Ins.	Ins.	In.	In.	Yrs.	
Oakbury Road to Stephendale Road	4,404		1899	14	5	3·40	1·51	0·10	0·093	20	
Stephendale Road to Townmead Road	2,133	..	1900	13	5	3·47	1·53	0·11	0·096	20	
Townmead Road to end of Wandsworth Bridge	1,155	..	1900	13	5	3·39	1·61	0·15	0·116	19	
Total .	202,268										

Rubber-Tire and Steel-Tire Effects.—There is also evidence in these figures that the rate of wear is decreasing. This is due to the fact that rubber tires are in more common use on all classes of vehicles, both heavy and light, and it is the tire that is taking a proportion of the wear which has been mainly confined to the paving. Wherever there has been a great increase in commercial motors, as in Wandsworth Bridge Road and New King's Road, the rate of wear is not decreasing to the same extent as, say, on the Fulham Road, this being due to the fact that steel tires are used on the majority of commercial vehicles.

A very fair idea of the rate of wear is obtained, and it will be seen that it works out at slightly less than 0·09 inch per annum over the principal roads. In many cases it is less than this figure, and in a few it is greater; but compared with the year 1909 it is a reduction of about 25 per cent., as the average rate of wear in that year was just below 0·12.

Repair of Roads. The table must be taken in comparison with a repair table. It will be noticed that the repair averages 1·59d. per superficial yard per annum, but in previous years it was only 1d. per superficial yard per annum.

It will not be out of place to give the record of the cost of repairs to the principal roads during the past ten years, and in Table IX. the cost of repairs are given worked out per superficial yard.

Average Cost of Maintenance of Wood Paving.—The average cost over the ten years is also given. The keeping of such a table is of great value to the engineer of a local authority in control of the roads, because he can by inspection estimate the expenditure that has to be provided for over a number of years, and an average sum can thus be allocated to each year which, if not expended in that year, can be carried forward to the next year, when double the amount of work may have to be carried

TABLE IX.

	1908–9.	1909–10.	1910–11	1911–12	1912–13	1913–14.	1914–15	1915–16	1916–17.	1917–18	Average Cost over 10 Years. *d* per sq. yard	Life of Pavement in 1918.	Average Life.	Traffic in Tons per ft. per day
	£ s d.	£ s. d	£ s. d.	£ s. d	£ s. d.	£ s. d.	£ s. d.	£ s d.	£ s. d	£ s d		Years	Yrs.	
48 Dawes Road . .	40 16 3 ·007	16 3 8 ·003	54 7 10 1·00	197 0 11 3·6	10 14 11 ·19	242 0 0 4·08	Nil 00	832 6 7 6 11	101 11 5 1 86	309 13 1 5·69	2 25	6 to 22	12	334
71 Fulham Palace Road . (Exclusive of tramway area 11,182 yds.)	167 10 1 2·45	133 0 4 1·95	13 11 11 19	129 18 9 1 90	112 8 5 1·64	727 6 4 13·59	266 8 8 3 90	82 9 0 1·20	Nil 00	470 7 11 6·89	3 37	10 ,, 19	13	338
30 Fulham Road . .	108 3 1 1·05	151 3 1 1·46	165 6 7 1 60	286 0 1 2 76	223 9 3 2·15	758 12 4 7·83	498 13 8 4 82	152 15 10 1 47	399 13 0 3 86	357 14 5 3 45	2 99	7 ,, 14	13	559
40 Harwood Road . .	26 16 4 1·25	2 6 11 ·11	8 2 9 ·38	7 18 8 37	31 16 9 1·50	9 6 9 43	19 19 11 ·33	47 13 0 2 22	108 0 9 5 04	231 17 7 10·82	2 24	10	10	353
80 King's Road . .	6 7 2 ·57	5 7 4 ·48	21 18 11 1·96	34 8 0 2 90	20 7 0 1·82	6 4 3 ·53	6 2 6 ·54	Nil. ·00	153 10 10 13·75	Nil. 00	2·25	11	11	307
83 Lillie Road . .	78 15 6 1·13	180 11 3 2 59	105 17 1 1 51	131 15 5 1 88	677 7 0 9 68	13 10 11 0 19	550 3 11 7 86	331 5 4 4 73	465 10 0 6 65	171 10 3 2·45	3 87	10 to 21	16	369
86 Munster Road . .	17 3 7 ·32	16 14 1 ·31	27 12 7 ·51	74 17 1 1·41	4 2 2 ·08	1 12 10 ·03	215 12 10 4·09	12 4 5 23	Nil. 00	195 12 7 3 71	1 07	12	12	
66 New King's Road .	72 14 6 82	219 7 5 2·47	70 19 2 ·80	464 7 7 5 27	66 9 10 75	347 16 9 3 94	720 13 8 8 17	183 5 1 2 07	247 16 3 2 81	288 19 8 3 27	3·04	6 to 24	21	302
57 North End Road . .	77 18 8 1·06	134 17 1 1·84	50 12 8 ·69	190 9 8 2 60	606 11 2 8·30	146 1 4 2·00	473 3 7 6 47	166 11 6 2 28	350 13 2 4·80	179 13 3 2 45	3 25	8 ,, 22	16	233
29 Wandsworth Bridge Rd.	34 18 8 ·52	105 14 1 1·62	87 0 0 1 31	732 12 3 11 10	586 2 8 8 88	446 12 2 6·77	235 7 2 3·56	269 6 8 4 08	67 9 0 1 02	170 15 0 2·57	4 14	13 ,, 23	20	255
66 May Street and Greyhound Road	27 7 7 ·53	36 17 5 ·71	50 11 2 ·98	9 19 11 ·19	72 12 2 1 40	2 18 7 06	315 14 11 6 12	93 1 0 1 80	Nil. ·00	81 7 3 1 19	1·29	18	18	.
12 High Street . . . (Exclusive of tramway area 3236 yds.)	Nil. ·00	36 18 4 2 15	Nil. ·00	17 11 5 1 02	3 17 10 ·22	Nil. ·00	22 12 4 1 32	35 14 5 2·08	117 5 2 6 34	Nil. 00	1 36	9 to 11	10	600
										Average	2 60	..	15	445

Assuming that the repavement costs 8s. per sup. yard for a life of 15 years, and 3d. per sup. yard for repair, the cost=9 4d. per sup. yard per annum, or £498, 10s. per mile. Dividing this by the total tonnage, *i.e* 445 × 30 ft road × 300 working days = 03d. per ton per mile. If the cost of the road structure was 5s. per sup. yard and its life 20 years, its repair costs 1½d. per sup. yard, and the traffic 112 tons per ft. for a 7-yard road, the cost per ton mile would be 0 08d.

out. By this means the rates can be equalised. It also indicates whether the rate of expenditure is going beyond its proper limits for repair.

Life of Paving.—The life of a pavement cannot be taken strictly by means of measurements—it is only a useful guide; it depends largely on the degree of satisfaction that is required in the locality. In some cases we hear that renewal cannot be delayed beyond nine years, where it is desired to maintain the road in perfect order; in one or two cases the period is fixed at even a lower figure.

But, in the writer's opinion, both these views are extreme; it may of course be necessary, when there are tram tracks, that the pavement should be renewed at more frequent periods than would be the case where the road surface is free from steel rails, which do not wear so rapidly as wood paving. It will be seen by closely examining the table that the only road with tramway tracks costs very much more for repairs than any of the other roads. The examination includes the age of the pavement, also the fact that only half the road width is maintained by the local authority, and it would be fair to say that only half of the traffic uses the area so maintained, the other half using the tramway area.

Renewal of Wood Paving.—It may be necessary, where there is a great intensity of traffic, to renew in preference to repair, because of the difficulty in carrying out repairs whilst the traffic is occupying the greater part of the road continuously.

Apart from these extreme cases, there is no apparent reason why stitch-in-time repairs should not be carried out, in which case the pavement will last twice the length of time mentioned above.

Weak Places.—The lack of attention to the weak places is the main cause of the damage that is subsequently made apparent. This is dealt with in detail when considering the problem of foundations of roads, which is explained on page 97.

As a rule soft-wood paving under moderate or heavy traffic does not require any appreciable attention during the first six or seven years of its life. There are cases, however, as will be seen from the table, where a new or re-pavement has been laid down, and where a number of repairs have been necessary in the first years of its life. These have been mainly due to subsidences of sewers, water-main difficulties, etc.

Analysis of Costs of Maintenance.—Assuming that a figure of 9d. per superficial yard is the limit of cost of the paving that is to be put down during its life of, say, twenty years or less, and that the pavement apart from foundation costs is 7s. 6d. per square yard, then 4½d. represents the cost of the pavement, *i.e.* the original cost divided by its estimated life. Suppose the cost of repairs during the first six years of its life is ⅓d. per annum, or a total of 2d. per superficial yard, the

repairs afterwards will be in a gradually increasing scale to keep it in a satisfactory condition; then during the next fourteen years of its life an average of 7d. per superficial yard per annum can be spent on repairs, so that the cost of the pavement during the twenty years would not exceed 9d. per superficial yard per annum. It will be seen from an examination of the whole of the cost of repairs of the roads under review that the costs have not exceeded 2·6d. per superficial yard per annum. It may therefore be taken that the cost of the paving has been considerably under 7d. per superficial yard per annum, and the most expensive roadway is under 9d. per superficial yard per annum. The traffic which these roads are being subjected to is given on page 4 and facing page 82.

Census of Traffic.—The next point to consider is the traffic which caused the wear on these wood-paved roads. A census was taken in March and April 1909 and again at the same places in June and July 1914 over a week at each of the twenty places determined upon.[1]

The daily and weekly averages are shown, and the weights taken per vehicle are also indicated; they are similar to those which have been determined by the Road Board. It is open to doubt whether they really represent the loads, because the probabilities are that on a principal road such as Fulham Road the weights would be higher than on the others, because the vehicles would be more heavily loaded, seeing that they are passing through the borough, whereas in the others the vehicles would be only partly loaded, through having distributed the goods they carried in the borough itself.

A comparative table has also been included which gives the percentage of decrease or increase on the census which was taken in 1909.

Rate of Wear according to Tonnage.—The tables facing page 82 give the results so obtained, and indicate the wear per 100 tons of traffic per yard and per foot of width of roadway per day.

It is perhaps necessary to make a few explanatory comments on the columns indicating the rate of wear.

The average works out at 0·027 inch per annum per foot of width per 100 tons of traffic per day. The width of the road has some influence on the wear, as it may unduly concentrate the traffic if it is narrow or spread the effect of the traffic if it is wide. The amount of steel-tired and horsed traffic also has its influence; for example, take the case of Wandsworth Bridge Road: here the percentage of both steel-tired and

[1] A map of Fulham showing the roads that are wood paved, asphalted, and sett paved will be found at the end of this volume. The positions where the census were taken in each case are also indicated. The periods were taken as representing the portions of the year when a fair average of the traffic could be secured.

horsed traffic is equal to about three times that of the average of the other roads, and it is a remarkable coincidence that the rate of wear is just about three times the average rate. Again, in the case of North End Road, the percentage of horsed and steel-tired traffic is about twice that of the roads showing average wear, and here again the rate of wear is nearly twice that of the average rate.

One is therefore inclined to draw the inference that, as there seems to be no other reason why the rate of wear in these cases should be so much higher, that the steel-tired and horsed traffic wears the road structure in a direct proportion to the ratio of percentage of such traffic to the total traffic passing over the road. But although this contention may be supported in some of the examples, there are other cases where such a rule does not apply, and therefore it is inadvisable to do more than note the fact for future examination.

The figures given in this edition are different from those mentioned in the first edition. There are several reasons for this: one is that the traffic in the 1914 census was taken over twenty-four hours, and in 1909 it was only over twelve hours; another is that the traffic has changed very considerably. There was in 1909 a much larger percentage of horsed traffic and steel tires, and therefore, as has been indicated previously, this would account for the reduced rate of wear.

There are several cases in the table where the measurements are omitted; this is due to heavy repairs having been carried out, and the figures would in consequence be misleading.

Rate of Wear in Direct Proportion to Weight of Traffic.—Where the road has been laid down over twelve years the wear is likely to be greater than on a pavement which has a lesser age, and this will account for ratio not being absolutely complete; but after full consideration it must be conceded that there is distinct evidence that the rate of wear is in a direct ratio to the weight of the traffic.

If a line of railway be taken as an example, it could easily be proved that the rate of wear is entirely and directly due to the traffic passing over it, and hence there is more justification for assuming that the contention set forth above is likely to be a true one. Rate of wear of a pavement depends upon the class of tires used upon it, and from the examination one may fairly conclude that rubber tires should be encouraged for vehicles traversing the road surface.

COMPARISON OF WEAR ON MACADAM.

The above figures do not prove what the wear of the surface of macadam road is. It, however, indicates the amount of wear on a material of a softer character than granite, and that the wear should not

be exceeded where granite is used in the road surface. It will be acknowledged that in the case of the use of granite setts the wear would not be as great as that shown for wood pavements ; and similarly, where the road surface is composed of an asphaltic material (fine sand or grit and bitumen or natural asphalt), the rate of wear is much less. Therefore, on a macadam road the wear due to tractional resistance is amply allowed for by assuming the same rate of wear on the macadam road as for wood paving.

In order to estimate the traffic on the macadam roads, all traffic such as motor buses, motor cabs, motor lorries, light tractors, trailers, and traction engines were eliminated—these being considered as through traffic not touching the bye-streets, which are macadamised. A proportion of the other vehicles may also be considered to be through traffic, but it was not thought advisable to exclude them, as probably some of the motor cabs and light motor vehicles may have their destination in the district where there are motor garages, or the roads are wood paved or asphalted.

In 1909, when there were 51 miles of macadam roads, it was thus estimated that 40 per cent. of the traffic of the main roads, which were wood paved, passed over these bye or subsidiary streets, and in this figure only about 50 per cent. of the horses touched these streets. The rate of wear then was $\frac{1}{8}$ inch on the whole of the wood paving, representing about 350 tons of wood fibre per annum. In 1914 the rate became reduced to $\frac{1}{11}$ inch, representing about 250 tons of wood fibre. Since 1909, however, the macadam roads are reduced in length by 10 miles, this area having been reconstructed with asphalt, so that now it is much more difficult to find the amount of traffic passing over the reduced area of macadam roads. In 1914 only 20 per cent. of the traffic was estimated to pass over the combined area of asphalt and macadam roads.

Weight of Manure, Grit, etc.—The amount of manure, wood fibre, and grit, including that from the side roads brought on to the wood-paved roads, was observed to be as follows :—

TABLE X.

Date.	Weight of Dust, etc.			Rainfall.
1909.	tons.	cwts.	qrs.	inches.
June 28	11	16	1	0·11
„ 29	14	18	0	nil
„ 30	14	15	1	0·16
July 1	14	2	1	nil
„ 2	14	16	2	nil
„ 3	14	14	3	nil
	85	3	0	

To still further test the accuracy of these figures, the weight of the manure, etc., was observed over a mile of the principal road :—

TABLE XI.—FULHAM ROAD (ONE MILE)

Dry Weather.					Wet Weather.				
Date.	Weight of Manure, etc.			Rainfall.	Date.	Weight of Manure, etc			Rainfall.
1910.	tons.	cwts.	qrs.	inches.	1910.	tons.	cwts	qrs.	inches.
April 4	1	6	2	nil	April 5	2	6	3	0 05
„ 7	1	1	2	0 01	„ 0	1	0	2	0·03
„ 8	1	1	3	0 01	„ 13	1	17	3	0 05
„ 9	0	19	0	nil	„ 14	1	15	3	0·11
„ 11	0	17	3	nil	„ 15	1	12	3	0·01
„ 12	1	4	0	nil	„ 16	1	4	1	0·07
	6	10	2			10	0	3	

Since these figures were taken, other records show that the tonnage of refuse taken from the wood-paved roads in 1913 was 75 tons, and in 1914 it was reduced to 68 tons. In five years the reduction is equivalent to 884 tons per annum, due no doubt to the decrease in horsed traffic and reduced wear of the wood pavements.

Effect of Rainfall.—The above figures in Table X. are interesting, because on June 30, 1909, there was a rainfall of 0·16 inch, which did not increase the amount of refuse as compared with the amount collected on the previous day, which was dry. But on April 8 and 15, with rainfall of 0·01 inch on each day, the latter day gave an increase of 50 per cent.

From the above figures it would be a fair assumption to consider the manure, etc., from the roads to be at the rate of 6 tons per week per mile. The amount therefore from the 12 miles of wood-paved roads would be 3750 tons, added to which would be 250 tons of wood fibre, making 4000 tons in all. As only 20 per cent. of the traffic passes over the remaining 51 miles, and 10 miles of these roads have been asphalted and are the roads that are the most heavily used, it would be a reasonable approximation to place the figure of the percentage of traffic passing over the 41 miles of macadam roads at 15 per cent.; therefore, if $\frac{1}{11}$ inch is the wear of the wood paving, $\frac{1}{16}$ inch should be the wear of macadam, which would be equivalent to about 270 tons of grit from the macadam per annum, making a total of 4270 tons.

Result of Tar Spraying and Asphalt.—In order to find whether these results could be obtained, tar spraying the surface of the macadam roads was begun in 1907–8 over 20 miles of these roads; as a consequence, the reduction of refuse collected from the streets was very noticeable. In 1908–9 the whole of the macadam roads were treated in a similar manner, and it has since been continued.

A chart showing the weekly collection and how the tar is affected by the weather is given facing page 244; the following totals, however, show the amount collected each year for the past ten years, and in this period 10 miles of the roads have been asphalted.

TABLE XII.

Year.	Tonnage of Refuse from Streets.	Year.	Tonnage of Refuse from Streets.
1907–8	13,409	1913–14	7,029
1908–9	11,600	1914–15	6,683
1909–10	10,159	1915–16	6,269
1910–11	9,038	1916–17	5,773
1911–12	8,309	1917–18	5,393
1912–13	8,275		

In the past three years there has been a distinct falling off of traffic in the bye-streets, due to the effects of the war; the horsed traffic on the main roads has noticeably decreased, so that it may be inferred that the last four years' results are due to the reduction in traffic. During the years 1911–14, the greater part of the 10 miles of roads that were asphalted was carried out. Although the actual reduction in manure collected on 12 miles of roads was 884 tons, a still further addition should be made to this figure in order to allow for the reduction that would be made from the same cause on the whole of the streets—it would not be more than 2000 tons per annum during the whole of the ten years.

Taking the figures for 1914, *i.e.* 6683 tons, the difference between the theoretical amount (4270 tons) and the actual amount collected is 2413 tons, *i.e.* about 60 tons per mile of macadam roads or 0·14 inch from the whole surface of the structure of those roads, which represents 60 per cent. greater wear than on the wood-paved roads with only 15 per cent. of the traffic.

Fifteen per cent. of the traffic in 1914 is equivalent to 30 per cent. of the traffic in 1909.

Since 1914, the amount of refuse collected from the roads has become

still further reduced, so that in 1917–18 it was only 5393 tons, or 1123 tons greater than the quantity that would be collected if the whole of the roads had been wood paved; but this reduction is explained above.

Allocation of Wear of Roads.—The conclusion that may be legitimately arrived at is that as traffic and weather are the two factors in the wear of a macadam road, the weather is directly or indirectly responsible for at least 90 per cent. of the wear and the traffic is only responsible for the remaining 10 per cent., or we may divide it more satisfactorily into three classes :—

1. Surface wear due to tractional resistance	=	10 per cent.	
2. " " weather	=	5	"
3. Interior wear due to traffic and weather	=	85	"

The latter is capable of being greatly reduced, even if it could not be entirely eliminated, and if a material can be found which could be so added to the structure of a macadam road which would eliminate the weather effect and make the internal particles immovable by the traffic, the life of the road would be extended over a very considerable period far in excess of its life as at present. There have been many suggestions and experiments by various people to effect this policy, and some of them will be dealt with later.

Economies in Maintenance Costs.—It will not be out of place to mention here the economies that have been effected by the work that has been done in this direction in Fulham. The cost of scavenging the refuse in a London district is considerable, and during the war the costs may be said to be abnormal, therefore present costs are not used, but it would not be at all an unreasonable figure to fix the cost of collection, cartage, and disposal at £1 per ton, therefore in the ten years the cost has been reduced by £8000; but, making allowance for the normal reduction of manure of 2000 tons, the net economy due to these methods of dealing with the roads is about £6000 per annum. To this must be added the cost of what would have had to be paid for replacing the material that is taken from the road in order that it should be maintained at its original level and contour; *i.e.* if 6000 tons of grit is taken from the structure of the road, the same quantity must eventually be replaced. A ton of macadam costs for material, labour, carting, rolling, etc., at least 25s., therefore the amount of the economy is increased by a further sum of £7500, making a total of £13,500 per annum, or £360 per mile of road per annum.

Macadam Road Expensive.—A careful consideration of the whole of the facts can only end in one conclusion—that the macadam road is an exceedingly expensive, wasteful, and unsatisfactory form of road structure

and should be dispensed with at the earliest possible moment and replaced by an impervious, homogeneous, and more satisfactory form of pavement, and that there is ample justification even for a wider application of the resolution passed by the Road Congress, which is mentioned at the beginning of this chapter.

Tar-Spraying Costs.—Each year's tar-spraying has cost from ½d. to ¾d. per superficial yard. The amount which has been saved by the reduction of watering and cartage has amply compensated for the cost so incurred, quite apart from the extended life given to the structure, the removal of the dust nuisance, and the better health of the inhabitants. Unfortunately, the tar does not last longer than twelve months, the weather has a deleterious effect on even this material, and the traffic in combination causes the necessity of an annual coating It is in the writer's opinion a cost which would not be incurred in the case of a bituminous form of road structure; that is to say, such a structure would be waterproof in itself, dustless, would not require annual treatment, and its maintenance ought for such streets to be less than ½d. to ¾d. per superficial yard per annum.

With a view of indicating a comparison of the amount of refuse removed from the roads which have been surfaced with asphalt, wood paving, and macadam, the following table is given :—

Road.	Extraneous Matter: Manure, etc., per Ton removed	Wear and Weather.
Asphalt	95	5
Wood paving . .	92 5	7·5
Macadam . .	53	47

The method of tar-spraying and permanent road construction that has been adopted has reduced this considerably, so that the figures now stand as follows :—

Road.	Extraneous Matter: Manure, etc., per Ton removed.	Wear and Weather.
Asphalt	95	5
Wood paving . . .	92 5	7·5
Macadam	70	30

Thus the life of the macadam roads has been increased by 33 per cent.

Comparison of Asphalt, Wood Paving, and Macadam.—The original cost of asphalt, wood paving, and macadam is in the proportion of 100, 75, and 35 (approximately); the repair is in the proportion of 100, 75, and 15 (approximately); the life is in the proportion of 10, 7·5, and 1 (approximately)—thus the comparison is 1, 1, and 2·5. The possibilities of economy by substituting a permanent paving for macadam that will last only 2½ times the life of the present water-bound macadam at the same cost or at an even increased price are therefore very considerable.

The reason why macadam roads are constructed on their present lines is mainly on account of their small first cost; they are quite 30 per cent. cheaper than wood paving, and even 40 per cent. cheaper than asphalt—*e.g.* in a road to be made of macadam there would be 18 inches of excavation, 12 inches to the foundation, and 6 inches for the macadam.

Macadam—

	s.	d.	
18 ins. excavation and carting	2	0	per sup. yard.
12 ,, foundation	3	0	,,
6 ,, macadam	3	6	,,
	8	6	

Wood Paving—

	s.	d.	
13 ins. excavation and carting	1	6	per sup. yard.
8 ,, foundation concrete	2	10	,
5 ,, wood paving	7	6	,,
	11	10	

Asphalt—

	s.	d.	
10 ins. excavation and carting	1	2	per sup. yard.
8 ,, foundation concrete	2	10	,
2 ,, asphalt	10	0	,,
	14	0	

Two-Coat Bituminous Paving—

Excavation and carting	1·2
6 ins. hardcore	1·6
3 ,, bituminous concrete base	2·0
1 in. wearing surface	3·0
	7 8

These figures will, of course, vary in other districts, but they form a reasonably representative comparison. In order to compare them, the cost must be taken over a period. Take the case that has already been mentioned, where the macadam road is repaired every two years; a wood-paved road would, under similar traffic, be repaved at the end of twenty years. The natural asphalt road would have a life of more than twenty years, but for the purpose of this comparison it is taken at that figure; the two-coat bituminous road would equally last fifteen years. A period of twenty-five years is given to the foundation, which would last for an indefinite period, but for the first comparison the period so given does not materially affect the figures one way or the other; it is probable that if a loan was obtained this would be an excessive life in which to repay the cost. Assume that repayment and interest is on the basis of 6 per cent.

TABLE XIII.

	5 Years.	10 Years.	15 Years.	20 Years.	25 Years.	Total.
Macadam—	d.	d.	d.	d.	d.	d.
Excavation and foundation . .	18	18	18	18	18	
Macadam	42·6	42·6	57·6	42 6	57·6	
	60 6	60 6	75·6	60·6	75·6	333
Wood Paving—						
Excavation and foundation	15·8	15·8	15 8	15 8	15·8	
Wood paving . .	27·0	32·0	32·0	54·0	27·0	
	42·8	47 8	47·8	69 8	42·8	251
Asphalt—						
Excavation and foundation	14 4	14·4	14·4	14·4	14·4	
Asphalt	36·0	36 0	41·0	41·0	46·0	
	50·4	50·4	55·4	55·4	60·4	272
Two-Coat Bituminous Paving—						
Excavation and foundation and base .	16·8	16·8	16 8	16·8	16·8	
Wearing surface . .	10·8	15·8	15·8	21·6	21·6	
	27·6	32·6	32·6	38·4	38 4	169·6

It will thus be seen that over a period of twenty-five years the cheapest form of paving is the two-coat bituminous paving, which is only half the

t of the macadam road; then comes soft-wood paving; natural asphalt :es third place, and a long way behind is macadam, which although ıaper to instal than natural asphalt and wood paving is more expensive ın the two-coat paving, and on account of the better wearing capacity ı latter is 50 per cent. cheaper over a period of twenty-five years. If venging and watering or tar-spraying is taken into consideration, the t of the macadam road would obviously be far greater than is here ıcated.

Even if the macadam road was repaired only once in four years instead two, the comparison would still greatly favour the bituminous two- ıt paving.

Effect if Weather is Eliminated.—From these analyses the conclusion 'orcibly brought into view that as the weather influences the wear of macadam road, *i.e* internal wear or attrition to the extent of 85 per ıt.—and this is exemplified by an examination of the wet and dry ts for attrition in Table VII., p. 60,—and it is due to this cause that surface structure only lasts two to four years, if the weather effects ıld be eliminated at a cost of two or more times the present cost, l the life extended proportionately, it would be a much cheaper rement, but even then not as economical as the two-coat bituminous facing material.

Damage by Studs and Steel Tires.—Much damage is done to all sur- es by the use of sharpened nails that are placed in horses' shoes in ıty weather and the spikes that are placed in the wheels of steam tor vehicles. In a case that came under the notice of the writer, a ucle was fitted with studs about 1¼ inch diameter; these studs cut into wood paving and made cylindrical hollows ⅜ inch deep, and the ck of the vehicle could be followed for over a mile of the road in the trict. Steel tires not being set to the contour of the road, the cutting ısphalt was distinctly observed, especially at junction of roads. When ıbstitution or modification for these is obtained, the advantages will considerable.

CHAPTER IV.

EFFECT OF TRAFFIC ON ROADS.

Weight of Traffic on Foundation and on Surface.—The thickness of the material forming the road surface should be considered. For this purpose a steam-roller was weighed, the back wheels being placed on the machine, and subsequently the front wheels, with the result that the weights were as follows :—

Back wheels . .	9 tons	0 cwts.	2 qrs.
Front ,, . .	3 ,,	16 ,,	1 ,,

Then an ordinary steam motor waggon was weighed carrying 5 tons of coal :—

Back wheels . .	9 tons	15 cwts.	1 qr.
Front ,, . .	2 ,,	5 ,,	2 ,,

The weight per inch of tire of steam-roller with a 5-foot 4-inch diameter wheel 15 inches wide = 632 lbs.

The weight per inch of tire of steam motor waggon with a 3-foot 7-inch diameter wheel 10 inches wide = 1092 lbs.

On a resilient surface the area in contact with the road was estimated to be 65 square inches in the case of the motor waggon, and 120 square inches in the case of the steam-roller; so that the pressure on the road surface may be assumed to be 72 lbs. per square inch in the case of the steam-roller, and 168 lbs. per square inch in the case of the motor waggon.

If a steam-roller has been rolling continuously a foundation of a road until the depressions have been removed, and a solid and unyielding surface is secured, it may be assumed that the foundation, if undisturbed, will in future withstand a pressure equal to the weight of the steam-roller per square inch of tire in contact with the surface. If the steam motor waggon just described had come upon the surface, its weight, being greater than that of the steam-roller, might disturb the surface and cause a depression; but if a cushion of a homogeneous matter was placed

between the tire of the wheel and the foundation surface so as to distribute the pressure over c times the area of the surface actually in contact, where $c=\frac{\text{pressure of motor waggon}}{\text{pressure of steam-roller}}$, the foundation would have to withstand no greater pressure than was the case when the steam-roller had finished working upon it.

Angle of Distribution of Pressure.—A square-based pyramid of circular balls can be placed in equilibrium, so that the pressure is transmitted at an angle of 30° from the vertical, if, however, the spaces were filled with a cementing material, pressure could be added to the top of the pyramid to a considerable extent before disturbing its equilibrium, thus showing that the angle of pressure has increased.

Suppose a mass of material cemented together of a length l is placed on two supports, a little less than l in distance apart. Weight can be added at the centre, and the pressure is transmitted to the supports, showing that the limit of the line of pressure will be horizontal or 90° to the vertical.

In a perfectly elastic material the intensity of pressure becomes greater as the surface is approached, and to resist this the material at the surface must be harder than below the surface.

Resiliency of Material.—If there is no *resiliency* throughout the material forming the surface, the intensity of pressure will be increased, because the weight is carried on a smaller area, and the material will the more rapidly break up. Professor Boussinesq calculates for an elastic material that the angle of pressure from the vertical is between 52° and 90°; but for road material, such as is described as homogeneous, the pressure is, roughly speaking, at an angle not greater than 60°, the material forming the surface of the road being in contact with the surface of the foundation throughout its length and width.

Pressure communicated to Surface—Thickness of Cushion required.—The pressure per inch of tire as given in the Motor Car Act is not the pressure which is being exerted on the surface; it is evident, if the road surface is of a yielding character, that there must be a certain length of the curve of the tire in contact as well as the width. There will be a less length of the tire of a wheel 3 feet 6 inches diameter in contact with the surface than would be the case of a wheel 5 feet diameter; and although the unit per inch of width may be the same in both cases, the pressure will be much greater from the smaller than from that of the larger wheel. In the example given above the pressure is in the ratio of 168 : 72, *i.e.* 2·33 : 1 and $c=2\cdot33$. Thus if the angle of pressure was transmitted at 45°, the thickness of the cushion should be 2·33 inches, but as the angle is 60°, the thickness of the cushion should be about

2 inches only. That 2 inches is sufficient for a road-surface material is borne out in the practice of laying only 2 inches of asphalt on a concrete foundation. It will be evident, therefore, that a good resilient surface need not be any greater than $2\frac{1}{2}$ inches in depth for an ordinary macadam road, and if a 3-inch thickness be laid, it allows for an inch of wear; any greater thickness that is placed in the road is wasted material, as $\frac{1}{2}$ inch of wear should provide for many years on an average road. Six inches is given to ordinary water-bound macadam, in order to feed the surface with material in place of that which has been washed or swept away. Four and a half inches of tar macadam is laid in the attempt to overcome or to compensate for inherent weakness in the material.

Voids in Road Structure.—The difficulty that has arisen in the past has been to discover the resilient surface. There is a prevailing idea that for road construction the elimination of voids between the stones is essential, and that the surface should be rigid and solid, but a close examination will show that the elimination of voids is not entirely desirable, as the less the percentage of them the more rigid, the more slippery, the less resilient and satisfactory will the road be.

Voids in Macadam.—A water-bound macadam road has voids ranging from 20 per cent. to about 10 per cent. Ordinary macadam of the sizes that will pass a 2-inch ring, if compacted together, has about 40 to 42 per cent voids. Hoggin, which is used as a binder, if the moisture is removed, has about 48 per cent. voids, so that if the interstices of the macadam in a road surface be filled with hoggin, the net voids will be

$$\frac{42 \times 48}{100} = 20 \text{ per cent.}$$

Of this 20 per cent. that is left in a dry firm road there is bound to be at least 5, and probably up to 10, per cent. of moisture, so that the voids in a properly consolidated road will be about 12 per cent. at the least, and more probably about 15 per cent. A pavement may be considered to be a mass of material non-resilient in itself, which, when bound together by an adhesive agent, encloses a series of air spaces. When a heavy weight presses on its surface, the air, having no outlet, is under pressure, and as soon as the weight is removed the air forces the material back to its normal condition. If the air is not confined, and is given the opportunity to escape, the tendency is for the material to compress until there is no further space for it to occupy, when it begins to break up.

From the point of view of horse traffic, the macadam road is the most satisfactory both in regard to resiliency, resistance, etc There is always a quantity of air spaces, because of the evaporation of the moisture. When the air is removed by moisture, the stones compress and abrade,

and it is then in its worst condition; when, however, the excess moisture is removed by evaporation or drainage and air forms part of the structure again, the surface structure regains its best form. If the macadam was bound together by a material of a plastic nature which was affected by atmospheric conditions, and the voids were reduced to a minimum, one of two procedures would be likely to take place: either the composition would break in its efforts to expand, or the liquid material would rise to the surface and flow away, thus causing disintegration and decay of the structure. This will occur, and is illustrated in many of the "pouring-in processes."

Voids in Asphalt and Wood Paving.—A fairly high percentage of voids is found in the asphalt that is laid by a number of firms, and it is the result of this percentage, properly and judiciously divided throughout the depth of the material, that is one of the causes of its success as a paving material. Another example of a successful road material is the soft-wood pavement; this class of timber has a higher percentage of cellular spaces than the hard woods, such as oak, jarrah, etc, and this is the reason why in some measure soft wood is generally more acceptable as a paving material than hard wood.

Compression in Asphalt.—If a new pavement of rock asphalt be examined and tested as to the quantity of mineral matter, etc., in a given area and as to its thickness, it will be found after a period of five or six years that the amount of mineral matter in the same area is much the same as when laid, but the thickness will, under traffic, have been reduced by $\frac{1}{8}$ to $\frac{1}{4}$ inch, this is due to a process of compression, which is continued until no further compression can be made, and real wear then takes place.

Compression in Tar Macadam.—Similarly with tar macadam, the material is usually very much thicker when it is originally laid than is the case twelve months after it has been laid; the compression in this case is much more rapid as compared with asphalt, and so the wear will commence at an earlier period

It would therefore seem that a satisfactory road surface could be made of a composition of material similar to the macadam that has been commonly used for many years, bound together with hoggin or similar material; but instead of water being used as a binder, another material of a plastic and adhesive nature should take its place, which should be waterproof and not affected by varying temperatures in the atmosphere.

Homogeneity and Resiliency as Factors in Road Construction.—In other words, homogeneity and resiliency are the leading factors to be sought for in road construction; while the percentage of voids is merely

incidental, the one cannot be secured without in some way affecting the other

If the material is not homogeneous and the composition is of varying sizes of stones, the traffic may transfer to one stone the whole of the weight of one wheel, and the effect would be to further transfer the weight in the direction shown by the arrows in fig. 12.

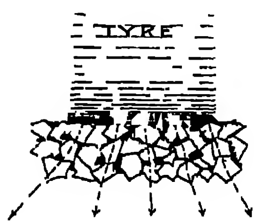


FIG. 12.

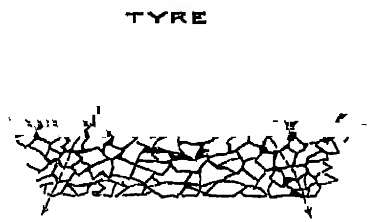


FIG. 13.

If, on the other hand, the top surface of this non-homogeneous mass is covered with a cushion of material of homogeneous substance, then the pressure is as shown in fig. 13.

The pressure should be transferred as shown in figs. 14 and 15.

In order to secure a homogeneous mass, it is evident that the materials forming the mass shall be of the same or nearly the same

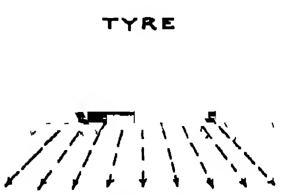


FIG. 14.

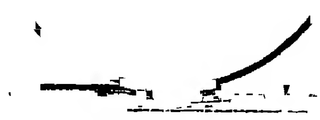


FIG. 15.

specific gravity, or, if this condition cannot be fulfilled, the agent which acts as the binder shall be so adhesive and so little affected by the atmospheric conditions that it does not allow the lighter material to move out of its original position.

Recuperative Power of Road Surface.—One other point is connection with the construction of a road surface is that the material forming the surface shall be capable of recovering its position when disturbed by traffic. This may be secured by the elasticity of the surface coating, or the surface may be of such a nature as to be capable of receiving back

the disturbed material when put back by succeeding traffic. If the material that is used as an adhesive agent does not quickly lose its adhesive characteristic, this latter condition should not be difficult to secure, but the matter is one that is frequently overlooked. This disturbance to the surface of a road is noticeable particularly at curves of a road, and is due to the effect of the quickly moving vehicles negotiating the corners or turns.

Strains in Pavement.—Another important characteristic is the *longitudinal movement.* In laying asphalt macadam with a heavy roller, the material while hot moves forward in the direction of the roller; this tendency is present in a structure that has set and is cold, and is evidently caused by the vehicles; it is frequently noticed in asphalt roadways, and in a different manner in wood-paved roadways.

Creeping of Asphalt.—Sections of asphalt roadways show waves as indicated in fig. 16. The line A B indicates the surface of the

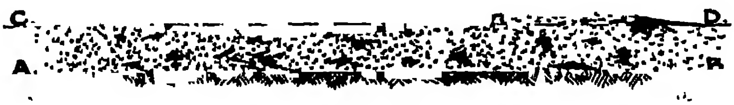


FIG. 16.

concrete foundation. The dotted line C D is the original surface of the asphalt, and the curved line C D is the waving condition which is frequently noticeable. This creeping may be explained in the following manner:—The asphalt is composed of fine carbonaceous limestone naturally impregnated with bitumen. This bitumen is, when solved out, found to be in a soft condition, and it has a flowing point near to the hot summer atmospheric conditions to which it occasionally is submitted. Owing to the thickness of the asphalt, the temperature is much higher at the surface than it is 1½ or 2 inches below the surface, and the very hot conditions are only for a very short period of the day; but it is at a time when the traffic is at its maximum. The bitumen is in a sense filled with fine filler dust, and this prevents the *bitumen* from flowing; but owing to the traffic forces which are capable of pushing the pavement forward, as illustrated in the next paragraph dealing with creeping of wood pavements, the thin layer of bituminous material is pushed out of its original position while the lower layers down to the concrete are not moved—hence a small ridge is developed which may increase in size. Under very hot conditions over a number of days there have been places where the concrete has been exposed, but these are exceptional.

In artificially made asphalt this condition has been overcome by

hardening the bitumen, and there are a number of instances where there are no observable waves in the structure, which indicates clearly that it is merely a matter of adjustment of the bitumen.

Where mastic asphalt is used on roads the wave movement is not noticeable, and where a hard bitumen has been employed it is similarly free from waves; but in these cases there is distinct evidence of contraction and cracking of the structure, which indicates that either an unsuitable bitumen has been employed, or the hardening has gone too far; the conclusion is that the consistency of the bitumen must be very carefully adjusted.

Creeping in Wood Pavement.—In wood-paved roads the difference is shown in the line of the joints, the surface still retaining its original face. A B (fig. 17) is a plan of the joint as originally laid at right angles

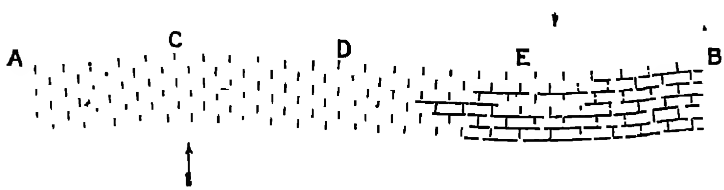


FIG. 17.

to the kerb; when, however, the road is submitted to heavy and fast-moving traffic, the joint takes the curve A C D E B, the traffic direction being shown by the arrows. This movement is due to the softening of the tar grout between the joints in hot weather.

It is only particularly noticeable where the blocks have been laid, without being dipped in tar, direct on to the concrete, and is not so apparent where the blocks have been dipped or so grouted that the pitch used in the grouting process reaches the concrete. The force therefore which is being expended is not very great, and from the fact that the movement is not spreading but reaches a limit without disturbing the even surface, also indicates that it is easily counteracted.

With a binding agent that is very soft in hot weather a movement will be in progress compounded of the effects of the weight acting vertically when in actual contact, and a forward movement due to the momentum of the vehicle; there is also the backward movement due to the friction of the driving wheels on the surface. These various forces have to be counteracted by the ductility of the binding agent. Where the pavement is non-resilient, the strain must be very considerable, the wear must also be immediate, and if the material is unable to resist, it will rapidly crumble.

ding agent may be very adhesive, but if it is not also ductile, il in road construction on account of the stress and strains to e structure is being continuously subjected; the one without · is in road construction hardly conceivable, but if a slightly but strongly ductile material was in competition with a very and only slightly ductile composition, the former would be of ›ater value, provided other features were equally good. The not be confused with the other.

Corrugations or Waves.—There have been many discussions years on the corrugations which appear on road surfaces, and ,hough they have been observable in roads submitting only to affic, are more apparent as a result of motor vehicular traffic. ıvements show this corrugation effect: it is very evident and ted on macadam, it is much less evident on wood pavements ıalt. Some attribute the cause to the rolling that is applied acadam road when it was originally laid, some attribute it to tions of the engine that propels the vehicle, others are inclined ıew that it is caused by a combination of the speed and the movement of the springs employed to take up the stresses in le.

g, however, that corrugations appear on railway rails, on the re of an overhead tramway system, on weavers' shuttles and s, it is not clear that it is caused by the rolling of the structure, ;gested in the case of macadam roads; further, corrugations n asphalt which is rolled not only lengthways, but crosswise alf circles, and the rolling is carried out when the material is the cooling of the asphalt would in all probability obliterate ıg effects which are suggested as the cause. Perhaps a conınswer to this suggestion is found in the fact that wood paveıow slight corrugations and are not submitted to rolling of

equally questionable whether it is due to the pulsations of the seing that it occurs on lift guides, on trolly wires, and weavers' A calculation shows that in the majority of the vehicles the ı in the cylinders takes place every 3 inches of the tread of the he driving wheel, whereas the period of these corrugations is inches, and in many cases even wider than this.

g Effect.—The suggestion that it is due to the speed and the the springs is more likely to be the cause. In every case where ons appear there seems to be a spring employed which has the t only of taking off the strain on the vehicle caused by any ut also it has the effect of causing the vehicle to keep to the

track more effectively than would be the case if it was not provided with springs. Travelling at certain speeds on a corrugated road, the corrugations are not so apparent to the person riding in the car. This is because the speed and period activity of the spring are in tune with the corrugations; but the effect on the vehicle, if it is travelling slowly, is very marked, because the speed and activity are not in unison with the corrugations. No surface can be made absolutely perfect, and the slightest depression or excrescence will start a motion in the springs; and these corrugations undoubtedly start from small beginnings. If the composition forming the surface is of a pliable or of an easily disturbed material, the effect on the vehicle is naturally exaggerated, as it would be in macadam or in an asphalt composed of bitumen of a low melting point.

No Remedy for Macadam. In the case of macadam road, practically speaking, no remedy has been found by any alteration of the composition of the structure; but in asphalt there is a remedy in the employment of a harder bitumen, or in so filling the bitumen that it is incapable of movement. If, however, one is inclined to try to effect a remedy by an alteration in one direction, the result is to obtain a defect in some other direction; the harder the bitumen, the more it is likely to contract in cold weather. If in the bituminous material large stones are employed to prevent movement by their penetration into the lower layers of the material, a form of disintegration is likely to be caused which is indicated in Chapter IX.

Pneumatic Cushions.—The writer has been impressed with the arrangement of pneumatic cushions to take the place of springs on vehicles. These cushions are placed on each wheel, and an apparatus is provided which automatically equalises the excess pressure caused by any shock. It is apparently very effective. It seems to work very much quicker than springs, and the description that was given to the writer by a person who had ridden in a car fitted with this type of cushion was that when the vehicle came on to a badly worn road the effect was that the sinking of the vehicle into the first depression was felt, but the reflex action that is apparent on a vibrating spring was not realised, and the car subsequently travelled the remaining portion of the road as smoothly as if it had been an even surface. If this is the case, it is surprising that this type of cushion is not in common use; the reason seems to lie in the fact that the cost of the fitting is at present very high, whereas springs are in comparison cheap. Modifications in the form of shock absorbers of various kinds have been fitted to the vehicles in common use, and the fact that these are popular would point to a more perfect form of cushion. Perhaps one of the objections to the

pneumatic form of cushion as is indicated lies in the automatic arrangement, and the fear that as all mechanical arrangements are likely at some time or other to get out of order it would, when such time did arrive, render the vehicle equivalent to one devoid of springs and become very unpleasant to use until the defects had been remedied.

Defective Structure. Apart from the vehicle and its effect on the road structure, there is an indication that the waves or corrugations arise from defective structures. It is very marked in water-bound macadam roads which are inherently weak and therefore liable to develop hollows; it can be greatly minimised in artificially made bituminous structures by adjusting the consistency of the composition, and in regard to sett-paved and wood-paved roads it is so little in evidence that it does not cause much or any inconvenience.

CHAPTER V.

FOUNDATIONS.

THE foundations of a road should be of a satisfactory nature. From the results of the previous examination of the effect of traffic upon roads it is clear that, provided the surface of the roadway is maintained in an even and regular manner, the structure under the surface, *i.e.* the composition of the material between the subsoil and the surfacing material, need not be more than about 4 inches in thickness if it can be maintained as a homogeneous mass.

Concrete.—In the list of roads mentioned on pages 4 and 5 are two, Dawes Road and Wandsworth Bridge Road. Both these roads carry heavy traffic, and in the case of Dawes Road a large sewer was constructed many years ago through the centre of the road: the trench of the sewer was about 8 feet wide. The wood paving had been laid over ten years when a water-main burst and the road pavement had to be made good. When all the rubbish had been cleared, it disclosed an extraordinary condition: quite one half of the full width of the road covered by the concrete, which was only 6 inches thick with an inch cement-rendering surface, was entirely unsupported; the length of this unsupported concrete was eventually found to be over 100 yards. The fact that the road had for the period of ten years not submitted to heavy repairs on this account, indicates that the concrete was of excellent material and that it was sufficient in strength to resist heavy traffic even when unsupported by the subsoil.

In the case of Wandsworth Bridge Road the paving had been laid down sixteen years and was requiring considerable repairs, mainly through the deterioration of the blocks under the traffic. As the traffic had mainly kept to the centre of the road, the writer determined to leave 4 to 5 feet on each side in and marry the new pavement into it. This was done in 1910–11 and 1911–12 (it is preferable to renew from side to side and sort the blocks at the sides of the road out for repairs).

A test was made of the depth of concrete, and in many cases it was only 4 inches thick, in the remainder 5 inches, but the concrete was sound and satisfactory. The traffic on these roads is given on pages 4, 5, and map (at end of book). Both these examples indicate that, given good surfaces, the foundation structure need not be of great thickness, as is so frequently advocated.

Object of Foundation.—This foundation structure is interposed between the wearing surface and the subsoil simply with the object of transferring the weight of the traffic over such an area that it will not cause the subsoil to submit to a greater pressure than it can withstand without being displaced.

Concrete 6 inches thick will withstand on a supported base a weight of over 20 tons to the square foot, so that concrete of this thickness is ample for the weight of any traffic that may come upon it, and especially

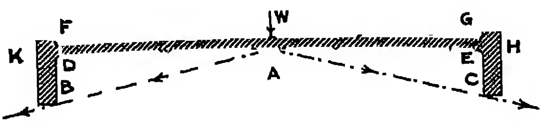


FIG. 18.

if on the concrete is a wearing surface in the form of a cushion. It follows therefore that the concrete when it fractures suffers from a greater blow than 20 tons, or that the subsoil under-support is unsatisfactory An unsatisfactory subsoil may, however, be contained by side supports and by that means made satisfactory, but even then it depends largely on the character of the subsoil as a whole.

If W (fig. 18) is the load, F G D E is 6-inch concrete laid on a subsoil of a loose character. Then by the side supports F D B K and G E C H the material forming the subsoil is contained, and as the material B D A E C is so enclosed, if the angle of friction is less than is shown by B A C, it is equivalent to a greatly increased thickness of concrete; but if the subsoil is of the nature of quicksand and can flow away in a sense in the direction A B or A C, then the concrete may become unsupported at A or other parts of the face D A E.

In places where the subsoil is unsatisfactory, it would be desirable to construct the roadway as shown in the sketch.

But there are other methods which may be equally satisfactory for weak subsoils, and the one that is proving popular is by the system of reinforcement.

Reinforced Concrete.—There are various systems of reinforcement of the concrete. They mainly consist of steel wire cross welded, expanded

steel, etc.; the mesh varies in size, 7 inches × 3 inches is frequently used, the rods being about $\frac{3}{16}$ diameter: the reinforcement is placed in the concrete from 2 to 3 inches above the bottom of the bed. Such a form of reinforcement has been used on very inferior subsoils with excellent results. Reinforcement is apparently only necessary on subsoils of this character. The writer was asked to try a sample of reinforced bituminous concrete to see whether it could be used to lessen the thickness of the concrete. The base on which it was to be laid was a good one, and only 1½ inches of bituminous concrete was laid on the reinforcement, the surface of the concrete was finished off with 1 inch of bituminous wearing surface.

On the adjoining area in the same road, submitting to the same traffic, the writer decided to lay precisely the same bituminous concrete without the reinforcement as regards thickness and area as that employed on the reinforced area. The results up to date are identical one is apparently no better or worse than the other.

Clay Subsoil. Those areas of roads which have subsoils of clayey material are probably the most troublesome of those that have to be contended with, and the principal work that should be carried out is the drainage of the moisture from the clayey material.

It has been estimated that well-drained clay will withstand a load of from 4 to 6 tons, whereas if the clay is wet and soft it will not withstand more than 1 ton per square foot; but the difficulty that has to be contended with is the spueing up at the sides of the load in other words, it must be contained in some manner.

In laying a road with only a thin layer of bituminous material about 1½ inches thick on an old foundation in very dry weather, there was an area about 10 feet square which was not observed when the road was being rolled, and which was found subsequently to be composed of London clay. The roller had no different effect on this area when it was being tested from the remaining area, and the road base was assumed to be satisfactory. As soon as the winter arrived this area was immediately apparent as wavy, and the composition cracked; it was taken out and the clay was exposed. Here the bituminous concrete was not sufficiently strong to contain the material within limited bounds. A depth of 3 inches of bituminous concrete was inserted under the surfacing material of a stiffer character, and no subsequent subsidence has occurred.

As the problem of the foundations of a road are of great importance, and very large sums of money have been spent in providing for a satisfactory foundation—in some cases it has been suggested that the depth should be 2 to 3 feet,—the writer considered, having in view the fact

that on a good new surface of wood paving on 6 inches of concrete the traffic never had any serious effect on the road surface, and it was only when the paving had been laid down a number of years that the defects in the foundations appeared, whether it was not advisable to make a test of the effect of a vehicle passing over a depression and over an obstruction.

Road Experiment.—The writer therefore devised a small machine which consisted of a couple of drums on which a strip of paper could be unwound and wound, the intermediate area of the strip passing over a flat surface. The speed of the travel of the paper was 18 inches per minute. The flat surface was then fixed to the body of the vehicle at the rear driving wheel, a pencil was placed on the axle of the driving wheel so that it

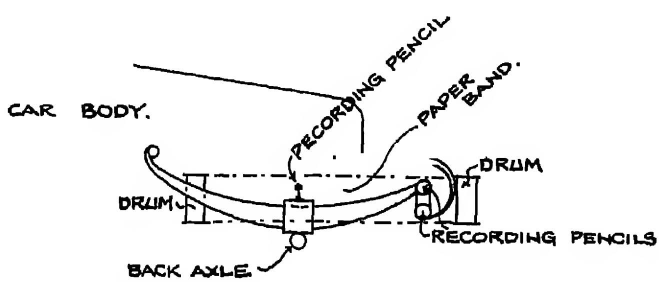


Fig 19.

would mark the paper, and two other pencils were fixed to the rear shackles of the spring—these also were so placed to mark the paper; the forward end of the spring was fixed to the body of the car. The rear end of the spring had a half spring also fitted to the body of the car. A depression was made $1\frac{11}{16}$ inches deep and 18 inches long, and formed so as to be similar to a depression that is frequently seen on a road surface.

The car was driven at a speed of from 5 to 7 miles per hour, and the front wheel passed over the depression as well as the rear wheel; figs. 20, 21, and 22 were the result. These diagrams will repay careful study; several tests were made and the results were precisely the same. The spring was drawn, and the effect was studied and calculations were made as follows:—

Resulting Diagram.—The diagram shows that when the front wheel passed through the hollow it had a reflex action on the rear spring, as is indicated by the projections at A and B, the movement of the body of the car relative to the axle being a minimum of $\frac{3}{8}$ inch and $\frac{1}{2}$ inch, and, while this action was operating, the rear wheels reached the hollow and the spring relaxed $1\frac{1}{4}$ inches, which is less than the depth of the hollow by $\frac{7}{16}$ inch, which represents the amount of compression taken

up by the pneumatic tire. The wheel as it rose out of the hollow was actually stopped in its forward movement, because the pencil marking is backward by $\frac{5}{16}$ inch. The movement of the spring through an arc the axis of which is 2 feet from the centre of the spring will scarcely account for a difference of $\frac{5}{16}$ inch, and as the movement of the paper was backwards the actual movement would have been greater than $\frac{5}{16}$ inch, and this is indicated by the slight loop at the point C at the shackles. Hence we must conclude that for a short space of time the car was actually stopped in its progress, and therefore whatever momentum the wheel had at that moment, it was entirely expended on the obstruction in the hollow. This is very important, because it emphasises the blow that the pavement and foundation are being subjected to, and if the same effect is produced by other and heavier vehicles, the blow that can be given to the structure is so great that scarcely any foundation would be able to withstand it for any length of time, especially if there was a continuous run of such vehicles passing over the hollow, as would occur in many roads.

Effect on Road.—Assuming the speed to be 5 miles per hour or 7 feet 3 inches per second, and the weight of the wheel at 6 cwt. 1 qr., the momentum (or blow on the edge of hollow) would be very severe.

Effect on Vehicle.—The actual deflection of the spring seems to have been no more than $\frac{7}{16}$ inch, and the weight necessary to cause this deflection would be 9 cwt.; the weight necessary to cause a compression of $\frac{7}{16}$ inch in the tire was nearly 7 cwt. The total vertical pressure was therefore 16 cwt, *i.e.* 2·66 times the load on the wheel.

A second trial on the same hollow (fig 21) gave a slightly different result; the compression of the tire was $\frac{5}{8}$ inch, *i.e.* 9 cwt., and the spring was deflected $\frac{7}{16}$ inch=9 cwt., making a total of 18 cwt. In this instance the speed was slower than in the first case.

Effect of Spring.—It will also be noticed that for $\frac{3}{4}$ second or a distance of 6 feet after the wheel left the hollow the spring had vibrated three times, and a deflection was still in the spring at that distance. From this we may gather that extra weight above the load was being sustained by the paved surface, and if the pavement was not sufficiently strong to resist this extra weight, hollows would appear at the three positions where the peak of each is indicated in the diagram.

The important factor is that the vehicle was stopped in its forward movement, and it follows that under such action it is only to be expected that the hollows will and must grow in size, and that even concrete foundations will give way; it also emphasises the importance of immediate repairs to any hollows if more serious damage is to be avoided.

Result of an Obstruction.—The third experiment (fig. 22) consisted of

an obstruction $1\frac{7}{8}$ inches in height over which the car passed. In this case the car was not hindered in its progress forward—it was delayed only. The tire took up a compression of $\frac{1}{2}$ inch, equal to about 7 cwt.; the body in relation to the axle had a total movement of 4 inches; the greatest deflection of the spring was 1 inch=14 cwt. The total effect on the car was equal to 21 cwt. on the pavement vertically. The spring was vibrated several times in a distance of 6 feet from the obstruction.

The conclusion is that the road structure is not so much affected by a temporary obstruction on a level surface as is the case when a vehicle drops into a hollow and has to rise out of it again.

CHAPTER VI.

TAR.

Moisture unsatisfactory in a Road.—The amount of moisture in a macadam road that is required to keep it in a firm condition is very small—probably about 5 per cent. If this is evaporated the road surface will ravel; if there is an excess it will become muddy. The watering of a macadam road is not carried out wholly to lay the dust, but to provide the moisture necessary to maintain the stone in its position and retain a firm and solid surface. From the foregoing it must be obvious that although the principle underlying the construction of a macadam road may be right, the use of moisture as a binding agent is wrong, if the road surface is to wear satisfactorily. It must occur to the student that any material which is easily affected by water must be avoided when considered in connection with the structure of a road.

Tar as Binding Agent.—It has therefore been the object of many engineers to dispense with the use of water altogether, and to that end many substitutes have been experimented with. Probably not one of the many materials has been so popular as *gas-coal tar*, and although it has been used in the British Isles for over thirty years in one form or another of road construction, and although it is a waste product, cheap and available at every gasworks, there are very few who thoroughly understand its composition, and fewer still, even of those who have used it most extensively, who will be able to lay down hard-and-fast rules which would enable it to be used perfectly satisfactorily in any specific form of construction for a road surface for varying degrees of heavy traffic.

The reason is not far to seek: tar is a very complex material, and no two samples are precisely alike, sometimes even from the same works.

Coal-gas tar is obtained as a waste product in the manufacture of gas from bituminous coal. The coal is placed in a retort, and by a process of destructive distillation the hydrocarbons of the original substance

are split up into hydrocarbons of a different character—some of which are in the form of a gas, others in the form of fumes, while the remainder is free carbon and coke. The gas is taken to the gas-holder, the fumes are condensed to various forms of oil and liquids, and the free carbon is carried along the passages and intercepted at a syphon of water, while the coke is taken from the retort. The oils, liquids, and free carbon are in combination known as tar Tar is also obtained from works manufacturing gas from oil (*carburetted oil-gas tar*), wood, etc., and from coke ovens, etc. It would require expert knowledge to distinguish one tar from another; in some works the oil tar is mixed with the coal tar, and the tendency is to increase this class of tar. Some time ago, as a result of the coal strike, a very large amount of oil was used in gasworks, and at one works in the north of England practically the whole of the gas was manufactured from oil. Even at gasworks the coal-gas tar will vary with the class of retort, the quality of coal, the temperature of distillation, and methods of treatment generally.

Composition of Tar.—A representative idea of the composite character of the tar is given in a table made by Mr L. F. Wright, and published in Lunge's book on *Coal Tar and Ammonia* :—

TABLE XVI.

	Distillation 600° C.	Distillation 650° C.	Distillation 700° C.	Distillation 750° C.	Distillation 800° C.
Gas evolved from one ton of coal in cubic feet . .	6600	7200	8900	10,162	11,700
Specific gravity of tar . .	1 086	1 102	1·140	1·154	1·206
Percentage composition of tar (by weight) :—					
Ammoniacal liquor .	1 02	1·03	1·04	1·05	0·383
Crude naphtha . .	9·17	9 65	3·73	3·45	0·995
Light oils	10·50	7·46	4·47	2·59	0·567
Creosote . .	26·45	25·83	27·29	27·33	19·440
Anthracene oils	20 32	18·57	18 13	13·77	12·280
Pitch . .	28·89	36 80	41·80	47·67	64·080

Higher Temperature, more Gas.—The above analysis demonstrates how, if the tar is removed at 600°, it will differ from that where the distillation is at 800°. The higher the temperature of distillation, the more do the forms of hydrocarbons which are stable at the lower temperatures become unstable and the more easily resolved into the gaseous forms of hydrocarbons. As the carbon is always in excess, it follows that there must, with every increase in the quantity of gas, be a similar

increase in the quantity of pitch, and of the free carbon in the pitch, the oils having gradually been broken up into gas and free carbon, and if the temperature is taken far enough they will disappear and the pitch become carbonised.

Tar may also be obtained from the carbonisation of timber and other vegetable matter. It is, however, principally the tar from gasworks, coke ovens, and blast furnaces that the road engineer is interested in.

The tar so obtained is a viscous fluid, dark brown in colour, and has a specific gravity varying between 0·95 and 1·2.

The tar from gasworks is of a varying character, because it is obtained from no particular standard form of coal; for example, the tar obtained from the carbonisation of the coal from Newcastle is rich in naphthalene and anthracene, that from Wigan has a higher proportion of benzol

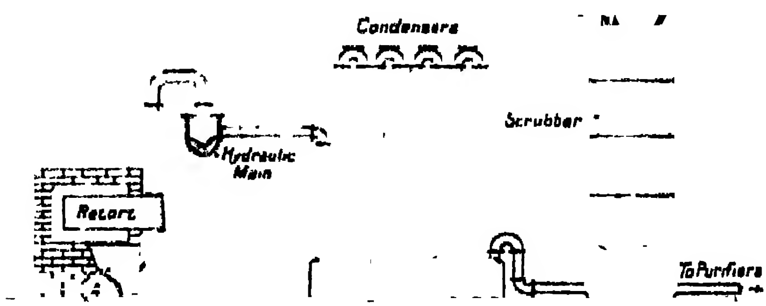


FIG. 23.—Diagrammatic section of gasworks.

and phenol; boghead or bituminous shale produce toluene and naphthalene and only a small percentage of benzene and anthracene; then cannel may also be used at the works, and carburetted water gas may be generated, the tar from which also varies; carburetted water-gas tar is a totally different kind of tar from coal tar, and should properly be kept separate.

The tars from the London works have a specific gravity of 1·18, and those from provincial works usually are about 1·1.

Although tar has been termed a waste product from the manufacture of gas, it can scarcely be considered as such now; it has a great value commercially, and the analytical study of this complex substance is engaging the attention of the highest talent in the world.

It is such an extremely complicated material that, so far, there have been found—15 series of hydrocarbons containing 2 to 25 compounds in each, 34 oxygenised compounds, 24 sulphuretted compounds, 32 basic and 8 non-basic nitrogenous compounds, besides numerous others which are constantly being discovered.

The tar varies in composition with the quality of the coal, with the type of retort, with the method of removing the gas from the retort, and so on. It is removed from the gas by passing it through water, *i.e.* the hydraulic main. It is deposited also at the condensers and scrubbers. From these sources the liquid is run to a well from which it is pumped into a tank, where the ammoniacal liquor is separated from the tar.

The tar is of a heavier consistency at the hydraulic main than from either the condensers or the scrubbers; it naturally at these points contains more of the volatile products.

Where exhausters are employed to remove the gas as quickly as it is formed in the retort, the gas remains for a shorter time in contact with the hot walls of the retort, and as fine particles of coal and coke are drawn away with the gas, this settles at the hydraulic main and hence the tar from these works will be found to have a heavy consistency.

Coke-Oven Tar.—The numerous coke ovens in this country are principally of the "Beehive" type, but they are being rapidly replaced by the closed-oven type. The tar which may be formed in the Beehive oven is, practically speaking, ignored; in fact, it is doubtful whether it would be economical to separate it. On the other hand, the tar from the closed-oven type (Semet-Solvay) is one that we may reasonably anticipate will give a more regular and even character than that from gasworks, because the coal used is of one class.

Dr Lunge gives the following analysis :—

TABLE XVII.

	Gas Tar.	Coke-Oven Tar.
	Per Cent.	Per Cent.
Water	2·9	2·2
Light oil	4·0	3·4
Benzol for aniline	0·92	1·1
Solvent naphtha	0·20	0·32
Creosote oil	8·6	14·5
Crude naphthalene	7·4	6·7
Anthracene oil	17·4	27·3
Pure anthracene	0·60	0·70
Pitch	58·4	44·3
Carbon	15–25	5–8

From 121 Otto ovens erected in Glassport, Pa., the tar, of which there is about 3·4 per cent., having a specific gravity of 1·17, contained the following :—

	per cent.
Light oil, 80° to 170° C.	3·7
Middle oil, 170° to 230° C.	9·8
Creosote oil, 230° to 270° C.	12·0
Anthracene oil, over 270° C.	4·3
Pitch	67·0
Water	2·3
Loss	0·9
	100·0

As about 10 gallons of tar are produced from a ton of coal, and about 20,000,000 tons of coal are carbonised each year in coke ovens, a large amount of tar might be anticipated; but as the Beehive type of ovens are installed in the proportion of about 3·5 to 1 of the closed-oven type, the amount of tar from that source is not as great as it might otherwise be. The conversion is taking place slowly.

The amount of sulphate of ammonia obtainable from a ton of coal is about 25 lbs.

Benzol can also be produced from this tar to a greater extent than from coal tar. As benzol is likely to become more and more in demand for motor purposes, and sulphate of ammonia is equally necessary for agricultural purposes, it is probable that the production of tar from this source will be increased.

In any case, the conversion from the Beehive to the closed-oven type is almost certain, because the financial aspect is so favourable.

TABLE XVIII.

	Semet-Solvay.	Beehive.
Number of ovens	12	12
Average time of coking (hours)	20	51½
Number of ovens discharged in 24 hours	14·4	5·5
Coal coked in 24 hours (tons)	70·53	27·31
Coke produced in 24 hours (tons)	56·74	17·04
Sulphate of ammonia produced in 24 hours (tons).	0·76	Nil
Tar produced in 24 hours (tons)	2·61	Nil
Yield of coke per cent.	80·7	62·3
„ NH_4SO_4	1·075	Nil
„ tar	3·69	Nil
Value of coke	£20·14	£6
„ NH_4SO_4	£10·72	Nil
„ tar	£6·14	Nil
„ products from 1 ton of coal	£8·08	£0·5
Cost of each oven	£320	£63
Duration of each oven (years)	10	5
Quantity of coke made in each oven (tons)	17·36	2·91
Cost of oven per ton of coke	0·017	0·023

The Semet-Solvay oven is a type which is becoming recognised as the latest and best of its class, and it is used in Belgium, France, and England. One of its principal features is the exclusion from the inside of the ovens of the heating gases.

The process adopted at the gasworks for the recovery of the tar is in a very large measure followed and adopted at the coke ovens. The liquid passes from a hydraulic main into the tar wells; tar is also obtained from the air condensers and water condensers; the latter are composed of a series of chambers filled with water through which the gases from the ovens pass and a proportion of the tar is left behind; it is then taken through a tar extractor; here it passes through very fine perforations, strikes a cool surface, and the particles of tar are brought together into a liquid and flow with the other tar to the tar wells.

Blast-Furnace Tar.—In Scotland there are a number of blast furnaces which are fed with bituminous shale which is suitable for the purpose. The yield of tar from these blast furnaces is from 5 to 10 per cent. of the weight of the fuel consumed. The same principle of condensing and cooling that has been described is adopted for the recovery of both the ammonia and tar products from blast furnaces. The tar from its chemical and physical properties is similar to the tar from gas retorts worked at low temperatures; it has a low specific gravity=0·95. The amount of tar produced from this source is equal to about $\frac{1}{6}$ of the tar produced from gasworks, and the amount produced from coke ovens is about $\frac{1}{8}$ of the gas tar.

Carburetted Water-Gas Tar.—Water gas is produced by passing dry superheated steam over white-hot coke: the gas produced has some heating value. In order to make this gas suitable for illuminating, it is passed through hot retorts with vaporised oil. The tar produced from this process is equal to from 10 to 20 per cent. of the oil used. It is not unusual to mix the tar obtained in this process with the tar obtained from the coal-gas retorts, but, as has already been stated, it is advisable that it should be kept separate, as the tar is totally different.

Oil-Gas Tar is not produced in this country, but it is to some extent used in Russia and America. This gas is produced by passing oil through red-hot tubes. The oil is decomposed, forming a gas which is used for illuminating purposes, but in the passing through the tubes some of the hydrocarbons are not decomposed, and form a tar.

Fractional Distillation of Tar.—Tar as it is removed from the tar tanks contains, as will be noticed from the analyses, ammoniacal liquor, water, light oils, etc. etc. None of these lighter products are useful in the tar used for road-making purposes, and it is necessary that they should be distilled off the tar. In some works the tar has only the

ammoniacal liquor removed, and the crude tar sold frequently carries 5 to 6 per cent. of water. The tar may be distilled so as to remove water and certain of the light oils, in which case it is called dehydrated tar; by raising the temperature in the still other oils are removed, and the tar becomes heavier and the process can be continued until pitch remains or carbon.

The specification of the British Engineering Standards Committee indicates that a standard can be arrived at. The method of distillation is somewhat as follows :—

The still is usually an upright cylinder of wrought iron with a dome-shaped top and convex bottom. The fire is bridged so that the flames reach well into the dome and then pass round the cylinder and from thence to the flue and chimney.

Steam pipes are fitted in the interior of the still with jets. At the head of the dome is fitted a pipe with cone-shaped entrance which passes to a condenser from which the condensed liquids are removed. Through the top of the dome of the still is placed a tar inlet, manhole, deadweight safety valve, overflow pipe, and thermometer; and the foot of the still is the pipe which discharges the distillate in the form of a heavy tar or pitch to what is called the smothering chamber.

The process of distillation is as follows :—

The still is filled with crude tar to the level of the base of the dome of the still: this is determined by means of a float. An air-cock provided in the crown allows the air to escape as the filling takes place.

The openings are then closed and the heating commences. The heat is maintained at boiling-point for some time in order to free the tar from moisture; this causes some slight explosion or bumping. The water having passed to the condenser, the next liquid to come is the light oils, and the receiver is changed. Greater heat is necessary to make the light oils come away, the heating being regulated to each change. Approximately the process is as follows :—

Dehydration	up to	110° C.
Light oil	,,	210° C.
Carbolic oil	,,	240° C.
Creosote oil	,,	270° C.
Anthracene	over	270° C.

These are the broad fractions that are generally adopted; in order to secure better isolation of the products, intermediate temperatures are used and separate distillation.

Dr Lunge gives the results of the treatment of 15,000 gallons of tar :—

TABLE XIX.

Time.	Temperature in Still Head.	Ammoniacal Liquor.	First Runnings Oil.	Light Oil	Carbolic Oil	Creosote Oil.	Anthracene Oil.	Pitch
	Degs C.	kg	kg	kg	kg.	kg	kg.	gals
8 0 a.m to 10 30 a m. (26½ hrs.)	80–98	880 sp gr. 1 00	440 sp. gr. 0·925					
10 30 to 11.30. .	167–228	..	.	250 sp. gr. 0 995				
11 30 „ 1 30 . .	228–252	.		..	520 sp. gr 1·015			
1 30 „ 4 00 . .	252–278	.		..	..	1800 sp. gr 1 045		
4.00 „ 6.30 . .	278–285				..		1450 sp gr. 1 095	9060

The ammoniacal liquor is treated and used in the manufacture of sulphate of ammonia; the light oils are redistilled and called light oil naphtha.

The distillation of the second lot of light oils is continued until the specific gravity is equal to 1·00. This fraction contains benzene, toluene, etc., and is very valuable; it can be treated and made into benzol. In the rectification of this distillate the residue is sent to the creosote oil well and the remainder is solvent naphtha.

The third section is in many works included with the fourth and called creosote oils; it is, however, this class that is used in the manufacture of disinfectants, colours, etc.

The fourth section is creosote oils and naphthalene, but there is in this oil anthracene, creosol, etc.; the naphthalene, however, is prominent to the extent of about 40 per cent. In the sale of creosote oil it is usual to stipulate the limiting percentage of naphthalene, otherwise when it is received it will be a solid substance under certain temperatures.

The fifth section or fraction is anthracene oil, sometimes called green oil, which is more often used for cutting back the pitch to a softer consistency; it is also used in the manufacture of alizarin.

The residue is called pitch, and at ordinary atmospheric temperatures is a hard, brittle, black substance; it can, by adapting the temperature of the still or by cutting back, be made into a soft pitch, moderately hard pitch, or hard pitch.

If the distillation is carried too far, the pitch becomes coke and damage may be done to the still.

Free Carbon—Effect on Adhesive Property.—The *free carbon*, therefore, in the pitch is a measure of the temperature at which the coal was treated. Obviously free carbon would serve no useful purpose as a constituent in road construction. It is, therefore, necessary to inquire

into the point where free carbon becomes a detrimental factor, taking into consideration the fact that coal tar cannot be obtained without a proportion of free carbon. The proportion depends in some measure on the manner in which the coal is treated in the retorts, and whether the retort is of the vertical type, the inclined type, or the horizontal type. In those installations fitted with vertical retorts (there are only a few in this country) the free carbon is said to be least in quantity, while the horizontal type gives the highest proportion. The reason why this is so is not quite clear, but it nevertheless is a generally accepted fact.

A proportion of the free carbon may be considered as a very near approximation to soot; the "blacks" that are given off when burning naphthalene will probably give some idea of the fineness and character of the free carbon. It is not generally regarded as an adhesive agent, rather the reverse, as it is often used as a temporary form of lubricant. Free carbon is also a well-known absorbent of moisture. However, it does not always follow that because a material by itself is a non-adhesive agent, if it is added to another material it will necessarily deteriorate the adhesive qualities of this material. As an example, bitumen is not necessarily adhesive until it has a suitable agent added to it which makes it so.

Tar Adhesive at Certain Temperatures.—In the manufacture of coalite, the tar which is obtained has only a low percentage of free carbon, but the tar can hardly be said to be adhesive at all, the oil being apparently in excess.

Tar is an adhesive material at certain temperatures, but if the free carbon was removed entirely it would probably become non-adhesive; therefore, laboratory experiments may prove that in the absence of moisture free carbon is the proper agent for making it adhesive. The question now arises as to the quantity. If a pitch has 33 per cent. free carbon, and the specific gravity of the pitch is 1·2, it follows that if the specific gravity of the free carbon is 1·5, the material which is distinct from the free carbon has a specific gravity of 1·05. Mineral matter in other bitumens of the best class is of a high specific gravity, *i.e.* about 2·6, so that the bulk of free carbon is 1·75 times greater than the bulk of the mineral matter in the bitumens. If the amount of mineral matter in tar is to have the same relative amount as in the bitumen, there should only be about 20 per cent. of free carbon in the pitch. The mineral matter in the bitumen has not an affinity for absorbing moisture, so that the excess of free carbon in the tar may have a detrimental effect in this way, as the more there is the greater will be the tendency to absorb moisture.

Absorption of Moisture by Tar.—The tests for absorption of moisture

by tar, as carried out by Mr Race, F.I.C., and explained in a very comprehensive paper published in *The Surveyor*, Nov. 25, 1910, would almost lead one to suppose that adhesiveness was inversely proportional to the amount of free carbon in the tar, and that the absorption of moisture was equal to one-third the amount of the free carbon.

Naphthalene.—These tests are not empirical, nor are they necessarily results due entirely to the presence of free carbon. There is in the tar a very considerable quantity of naphthalene, much of which is removed when the tar is distilled to pitch; but if there is in the tar any naphthalene, it is quite possible that this substance may have had some influence on the absorption of moisture, as it has an even greater affinity for moisture than free carbon.

Distillates from Tar.—In distilling tar, when the temperature reaches 180° C. naphthalene begins to come over with the creosote, and continues to come over when the temperature reaches 250° to 270° C., so that the creosote and the anthracene both have a proportion of naphthalene which has to be removed by settlement. There is a quantity of naphthalene in solution in commercial creosote and anthracene oils. It is therefore probable that in any pitch or tar there will be at least 5 per cent. of naphthalene, and it must therefore be accepted that these two substances, naphthalene and free carbon, are inherent difficulties, which may become important when applied to such works as road construction, subjected to long periods of moist conditions, and the continuous beating and pounding of traffic.

In the majority of cases of failure that have come under the notice of the writer, there has been distinct evidence of moisture in the structure. The reason for failure, however, cannot be assigned definitely to the free carbon or the naphthalene, as the method of construction in each instance gave some encouragement to moisture to enter the structure. If moisture does penetrate to the interior of the road surface and a frost intervenes, the adhesion of the stone is likely to be broken, and as the moisture would be retained there would be no subsequent adhesion. Thus the road would be broken up without the material having been worn, or its use exhausted.

London Pitch.—From inquiries in London, the amount of free carbon in the pitch varies between 26 per cent. and 33 per cent. As the tar from the gasworks in and about London is nearly one-quarter of the tar thus produced, it becomes very important to test the material thoroughly before arriving at the conclusion that the presence of free carbon in the above proportions is a disadvantage. More especially is this the case when prominent advocates of tar in road construction regard the presence of free carbon in roads with comparative indifference, and mention roads where such tar has been used as successful examples.

The difficulty seems to be in repeating the examples in other districts with a different class of traffic.

Tar Producers and Tar.—The British Engineering Standards Committee have, as has been previously stated, published a specification of various classes of tar (see Appendix).

This specification is doubtless one that tar producers can accept and give to road engineers, and one that road engineers can accept. It is a serious attempt to standardise the tar for road structures. But whether the tars so specified are such as will meet all the requirements is doubtful. They are based on the knowledge that was prevailing at the time the specifications were considered and made, and doubtless had to accord with the requirements of the trade in respect to those oils distilled from crude tar which have a high commercial value. It is quite probable that it is due to this that certain elements remain in the tar, as specified, which could usefully be eliminated. For example, the tar, as specified, and which may be used in a sealing coat or tar-sprayed coat will, under heavy traffic, wet weather, and a low atmospheric temperature, develop into a slimy mud. It is evident that the tar under such conditions becomes emulsified. What causes this feature to develop? Is it the naphthalene that is allowed to remain in the tar or the free carbon; or is it some of the third or heavy oils which apparently the atmosphere seems to affect so that oxidation takes place, or the sun or atmosphere is able to break up and allow a portion to volatilise? Because, whenever any of these tars are exposed to the atmosphere, the surface quickly hardens.

Obviously this characteristic of tar is a detriment to its successful use as a medium in road construction under heavy traffic conditions.

That there are elements in the specified tar which are unsatisfactory must be admitted; in some cases it has been noted that a percentage of tar acids are included in specifications of creosote oil, which is used for the cutting back of pitch; tar acids are useful for the preservation of timber, etc., but do not seem to the author to have any particular value for road-constructional work, and it would seem from the above-mentioned specification that these tar acids must be in the tar so specified, and it is possible that these or some other oils or acids may have the deterrent effects.

There is a wide field for investigation in tar for road work, and the writer is convinced from the results which he has secured that a careful and systematic examination will discover in this material a much more valuable product than it is at the present time. The analyst must work with the engineer, who knows what is wanted and what is to be sought for. It may be that as a result of this investigation certain portions may be removed with advantage; on the other hand, it may be that certain

added material will prove to be an antidote and remedy the defects and be more economical. In any case, it is a subject that will well repay investigation if a successful material is developed. Up to the present, experiments with different materials have been tried with no particularly satisfactory results and with no apparent method.

Tar is relatively a cheap material in this country, being about one-third the cost of bitumen in normal times; but unless the results secured from its use are equal or nearly equal to those obtained from the use of bitumen, it may even at such a cost be the more expensive, as has actually proved to be the case in several instances.

Dehydrated Tar is the tar which has been heated at 110° C. (230° F.); there should not be in this tar any greater percentage of light oils or moisture than 1 per cent If a thicker consistency is required, then the distillation can be carried to 210° C. (410° F.) to remove some of the creosote and naphthalene, or by a still further distillation up to 270° C. (518° F.) to remove the naphthalene and a portion of the anthracene. The temperature should not be raised above 270° C. (518° F.), as the pitch above this temperature begins to decompose and carbonise. It is therefore necessary to continue the heating by means of steam-piping, the steam being at a pressure of 50 lbs, so that the temperature is not increased. The pitch thus obtainable is "hard" or "soft," depending on the amount of oil distilled off.

Method of Testing Pitch.—A simple method of testing for the quality of pitch that is required is to take a small quantity in the form of a cube (½ inch), pass a red-hot wire through the centre, and suspend the wire horizontally under water, then gradually heat the water up to 150° F., when the pitch should leave the wire: this temperature may be termed its melting-point.

Composition of Pitch.—Pitch is "bitumen" and extraneous matter, such as free carbon, residual coke, etc. (bitumen being understood to be a substance that is soluble in carbon disulphide).

Test for Free Carbon.—This is as follows:—A quantity of tar is treated with carbon disulphide or hot benzine until the extracted liquid is not discoloured: the residue when dried is free carbon.

Fixed Carbon.—Free carbon must not be confused with *free carbon*, the test for which is determined by taking a gramme of tar and placing it in a platinum crucible, tightly covered, and then submitting the crucible to a bunsen flame 9 inches long, the bottom of the crucible being placed 2½ inches from the bottom of the flame: the residue after seven minutes is fixed carbon.

Signification of Fixed Carbon.—Mr Clifford Richardson, in dealing with the question of fixed carbon in bitumens, says: "In the determina-

tion of the amount of fixed carbon which any native bitumen will yield when heated to a high temperature in the absence of oxygen, data are obtained which are of great interest as showing the relative proportion of carbon and hydrogen in the bitumen under examination. In the case of the paraffin hydrocarbons of the formula C_nH_{2n+2}, no fixed carbon is left on ignition, while the amount increases with each diminution in the proportion of hydrogen to carbon, until in grahamite as much as 50 per cent. is found where the relation of carbon to hydrogen is 8 to 1."

A high proportion of fixed carbon in a bitumen is an indication of the severe treatment that the material has undergone in the course of its production.

Uncertainty of Effect of Free Carbon.—The Road Board's original specification, which has given place to the British Engineering Standards Specification (see Appendix), gave the percentage of free carbon as 16 per cent., but this was amended to 20 per cent. owing to the difficulty of obtaining tar with such a percentage as is indicated, and to the uncertainty which prevails as to whether the higher percentage is any greater detriment to its use.

Adhesion of Tar.—Mr Walker Smith, who has closely examined into the peculiar characteristics of tar, has among other matters given a table of its adhesion and also its re-adhesion at two different temperatures. The figures have been amplified in a subsequent paper published in the *Proceedings Inst. C. E.*, vol. clxxxvi. The table is most interesting, as it demonstrates the erratic qualities of the tar, probably obtained in the ordinary way, and without being brought to any specific standard. Each of the tars had different specific gravities, and consequently it can be assumed that they differed in consistency.

TABLE XX.

Material.	Adhesion.			Re-adhesion.			
	55° F.	110° F.	Per cent.	55° F.	Per cent.	110° F.	Per cent.
Coal tar 1 .	45·75	35·50	−22	41·75	− 8	12	−67·9
,, 2 .	51 20	20·00	−60	20·00	−60	8	−84·9
,, 3 .	49·50	83·25	+68	54·25	+ 9·6	44·25	−16
,, 4 .	150·00	204·00	+36	89·00	−40	117·00	−22
Tarvia 1 .	41 00	47·00	+14	33·00	−19	15	−88
,, 2 .	131·00	143·00	+9	75·00	−42·7	53	−60

No standard has been laid down as to what is the amount of adhesion that is required in a good road construction, so that there can be no comparison; *prima facie*, Nos. 3 and 4 give the best results.

That adhesiveness is necessary in a binding agent is a *sine qua non*; but adhesiveness is not a serious item. For instance, if a stone is so surrounded with or embedded in other material, while the actual adhesiveness of the binding agent between the stone and the material in which it is embedded is small, as it is in a water-bound macadam road under ideal conditions, its movement is confined to the minutest limits; the stone cannot break away from contact with the other material, and therefore adhesion plays a somewhat unimportant part, and ductility becomes a much more sought-for characteristic

Importance of Adhesion in Tar Macadam.—In the usual methods of tar-macadam construction, the adhesiveness and re-adhesion would play an important part, because the stones are not embedded in a material but have comparatively large portions of the stone unconnected and therefore subject to considerable movement.

Atmospheric Temperature—Effect on Roads.—A roadway surface is exposed to the full rays of the sun, and a black substance such as tar will retain the heat for a longer period than a lighter-coloured surface. In London, during July 1910, a temperature of 121° F. was recorded, but in July 1911 the temperature went up to 132° F. These high temperatures have therefore to be taken into consideration, but it does not follow that because the surface has a high temperature that such a temperature would be obtained 2 or 3 inches below the surface.

The other extremes are also to be considered: the winter temperature will go to about 25° F., summer evenings and nights will give a temperature of 53° to 55° F. So that, if an average is taken, possibly the latter would prove to be a fair figure. In road construction the average cannot be taken, but the limits when the traffic is exerting its influence on the road, *i.e.* between 9 a.m. and 6 p.m., and during those periods the temperature may be about 30° F. in the winter and 120° F. in the summer

Viscosity of Pitch.—A pitch that was used for grouting a macadam road was examined and tested with the object of finding the viscosity at various temperatures. The test was made by noting the depth a weighted needle would penetrate the pitch in one second.

At 40° F. the penetration was nil.
,, 50° ,, ,, ,, ,, 1 mm.
,, 80° ,, ,, ,, ,, 8 mm.
,, 90° ,, ,, ,, ,, 16 ,,
,, 100° ,, ,, ,, ,, 28 ,,
,, 110° ,, the pitch was too soft to record the measure.

This sample would, therefore, prove to be too hard in winter months and too soft in the summer weather.

Variations could be made which would give a penetration at 40° F., but the softness would be reached at a lower temperature than 110° F. The addition of slaked lime would probably enable the mixture to be measured by penetration at 110° F., because the lime would prevent the pitch from moving during the time of the test. Either creosote oil or anthracene oil is used to soften the pitch (see the British Engineering Standards Specification for the method of heating and the proportions to be used).

If pitch and creosote oil is placed in a pan and heated, it will be noticed that when the temperature rises to 160° F. fumes become visible, which shows the low evaporative power of the oil. If the temperature is raised to 270° F., which is the usual temperature for making the combination, it must be anticipated that considerable volatilisation will have occurred, and if the pot is left simmering for any lengthy period at even a lower temperature, the viscosity will have altered in a very marked degree.

Volatilisation of Tar.—In this connection Mr Walker Smith gives a very striking example, in his treatise on *Dustless Roads*, on the evaporation of tars at ordinary temperatures of 60° F. and 110° F.

TABLE XXI.

Material.	Sp. gr.	One Week at 60° F.	One Week at 110° F.[1]
Coal-gas tar	1·23	0 23	1·10
Coke-oven tar	1·21	1·70	8 80
Distilled tar	1·195	0·74	3 20
Tarvia	1·245	0·50	2·13

[1] The figures under this head are in excess of those at 60° F.

In the paper read before the Inst. C.E., vol. clxxxvi., the same author gives perhaps the best example of a standard for tar that can be made. He limits the evaporation of tar to 1 per cent. at 60° F. in one week.

It would seem that this is the very factor that ought to be eliminated altogether, but the possibility is doubtful.

It becomes evident that as it is the oils which keep the pitch in a pliable condition, any reduction by evaporation must harden the pitch and gradually make it brittle. If 1 per cent. can be absorbed in one week at 60° F., as there is only about 20 per cent. of oil in the pitch, it is con-

ceivable that twenty weeks' exposure would remove the softening agents This is not likely to be the case in any road construction. The surface of the tar hardens, and this will prevent the interior oils from being absorbed into the air, but any cutting into the surface of the tar, and consequent exposure of a new surface, would cause the reduction as a matter of course.

Hardening of Tar.—In road construction, therefore, it might be taken that the tar should not be hardened by the addition of lime sulphur, or resin, because the volatilisation that will go on during its life in the road would perform the necessary hardening. But it is found desirable to add a little resin and a, comparatively speaking, large quantity of oil, and also a proportion of lime. The oil softens the pitch, the resin hardens, or, preferably, raises the melting-point without materially altering the effect of the oil. The lime, if carefully placed in the mass by sprinkling and constant stirring, will act as a preventative of the flowing of the material when it reaches that stage through excessively high atmospheric temperature. Sulphur would act as a hardening agent, but its use is not usually considered advisable.

Examples of the hardening of tar when submitted to atmospheric conditions are plentiful, in the grouting processes and on the roads which have either been tar-painted or on roads which have been laid with tar macadam. In July and August of 1911 a road was coated with stone and afterwards pitch-grouted. The weather was exceedingly hot and dry, and the pitch was noticed to be in a flowing condition, leaving the middle portion of the road for the sides. In September, on a day which was equally hot, there were no evidences of the pitch flowing, and the stickiness of the pitch had entirely disappeared. The intervening month had been very hot, and there is no doubt that the volatilisation had been considerable; and the impression given was that the tar was dry, hard inclined to be slippery, and that it would not take very much more of such severe atmospheric conditions to make it easily crumble. Some portions were soft, and it may have been due to faulty mixture. This would probably be an exceptional case, as the pitch ought not to have deteriorated so rapidly.

TAR-SPRAYING.

The hardening and subsequent disintegration or breaking up of tar is seen more frequently and more strikingly in tar-painted or tar sprayed roads.

The tar is laid on an existing water-bound macadam surface, which must be fairly true and dry, by means of a brush or mechanical spray While the tar is in its fresh, adhesive condition it is coated with a layer

of fine chippings or with sand. In some cases this layer is so thick that no tar is at first visible. It is then either rolled with a steam-roller or the traffic is allowed to work the chippings in In other cases the material chosen is merely sprinkled lightly over the tar, so that it is not at all hidden from view.

Within a few hours the sand is absorbed by, or is coated with, the tar. Probably before the end of a week, and especially so if the weather is very hot, the surface becomes oxidised and hardens; this coating is tough and resilient, and makes a very acceptable roadway. After a time the traffic, if it is continuous and heavy, will affect it; it becomes dry, and a brownish powder is seen on the face of the road. This appears to be the first sign of disintegration, but it is not until the weather turns cold and wet or damp that the breaking up of the tar takes place in any marked degree.

It is more severe where the chippings and sand have been heavily laid on the coating of tar, as may be explained by applying the defects that have been elucidated in the foregoing paragraphs. The tar is in a very thin layer on each stone, therefore greater volatilisation has taken place than would have been the case where the chippings had been merely sprinkled over the tar-coating. The tar is also in a very fluid condition, and while it is hardening the chippings are moved about by the traffic, continually exposing new faces and encouraging volatilisation in the highest degree. The thin sprinkling of sand (the writer adopts this method and sweeps the surplus away after forty-eight hours) leaves a greater body of tar on the surface, and tar is more adhesive to itself than to outside bodies. It must be borne in mind that the tar that is used for tar-spraying or tar-painting is dehydrated tar, *i.e.* the tar from which the water, naphtha, phenols, etc., have been removed; it still retains the naphthalene, the substance which absorbs moisture.

Moisture a Deteriorating Factor.—If a piece of the tar-coating, which is more or less easily peeled off the surface, is broken, there is distinct evidence of moisture, and in some cases a crystalline structure. It must therefore be anticipated that moist and wet weather will have a deteriorating effect on the coating, and it only requires sufficient traffic to complete its destruction.

Softening Pitch.—To use tar which has had the naphthalene removed would be a somewhat costly procedure, as it would involve distillation to pitch and softening back with heavy oils, and the amount or proportion of oils would be so high that it would take a much longer period to set, quite apart from the difficulty of laying it and the greater excess of oil over the quantity that is in the dehydrated tar, the oils of which are lighter and more evaporative.

Effect on Macadam.—One of the disadvantages of tar-spraying or painting is the effect it has on the macadam underneath. The coating of tar is laid in order to prevent any moisture from penetrating to the macadam structure; but as the macadam is dependent on a certain percentage of moisture in order to maintain its firm condition, and as the tar is only placed on the surface of the road when the latter is in a dry condition, a certain small proportion of the tar, which is in an attenuated condition, or of some of the oils from it, penetrates the fine material between the stones, evidence of which is the brownish colour imparted to the fine material. This removes the binding properties that previously existed. While the tar-coat is whole, no damage is done, but immediately the coating is worn through by the traffic, the macadam rapidly ravels and holes are formed. It therefore becomes necessary to carefully watch the deterioration and wear of the tar-coat, and recoat this portion before it is too late.

Affinity of Limestone for Tar.—Limestone or certain classes of limestone appears to have a greater affinity for tar than any other stone, and the above conditions do not seem to apply to such an extent as they do with granite or with flints, but on limestone the surface becomes much more slippery, and consequently less acceptable to users of the road.

Tar-spraying an Annual Process.—It is recognised that tar-spraying must be done *annually*, on account of the volatilisation which goes on. The oils which keep the tar pliable to a large extent disappear, and if it is left longer than about twelve months, the coating rapidly breaks up by ordinary traffic conditions. The annual dressing is required, therefore, to impart "liveliness" to the old material; thus each year the coat becomes thicker, and at some time or other will have to be removed. It is therefore desirable that the first coat should be as lightly laid as possible, and just enough for the purpose—the writer spreads one gallon over 9 to 10 superficial yards. In the majority of roads this appears to be quite sufficient to lay the dust, but there are many roads where this coating is worn away in about two months, when a second coat is applied, and where necessary a third coat; by the time the winter arrives, the road is no worse than it was in the days when tar-spraying was not adopted. The only objection that is raised is that the dull black appearance of tar-spraying is an eyesore; but the advantages are admitted.

There is no doubt that it is an economically successful method of treating macadam roads. The chart at end of book shows what has been done in one of the boroughs of London, and there are many other districts which could testify to equal, if not superior, results than are there indicated.

Fig 24 —Tar-sprayer.

There are many roads where tar-painting is almost of permanent advantage, *i.e.* roads lightly trafficked, as few known processes of construction would compare with it in cost, notwithstanding its disadvantages.

However, it can only be regarded in the majority of cases as a palliative, a temporary expedient, and only to be adopted pending the time when a satisfactory, permanent, impervious, and cheap (in first cost) pavement can be adopted to replace the water-bound macadam road, combined with the annual tar-painting.

Machines for Tar-spraying.—There are quite a number of machines on the market for the purpose of tar-spraying. The principle in each is very similar: the tar is heated in a tar-pot to a temperature of about 250° F., and then pumped either by manual labour or by means of steam power. Passing through an air chamber which equalises the pressure, the tar is forced through a small pipe at high speed to a nozzle, impinges on the sides, and is whirled round and broken up against a plate, issuing forth in the form of a fine spray on to the surface of the road.

Mechanical Tar-spraying Machines.—The illustration facing this page shows one of a number of forms of tar-spraying machines. The tank in front of the tar boiler is filled with tar, and a pipe connection with a hand pump joins the tank with the boiler.

The boiler is partly filled with tar, and a fire heats it to a proper consistency, and as fast as it is sprayed on to the road the boiler is supplied with tar at the same speed by means of the pump and pipe connection; by this means the heat of the liquid is constant. When the tank is emptied, it is unhitched from the tar boiler and another full-loaded tank is hitched on to the boiler. By this means the work is continuous.

The tar is pumped by hand and forced through a pipe at the end of which is a specially designed nozzle which breaks it into exceedingly fine molecules.

Fig. 24A shows a 1000-gallon tar-spraying machine complete in itself; it is its own tar tank and boiler, the heating being done by means of steam coils placed on the bottom of the tank. The steam is taken from the boiler of the engine which is used to drive the vehicle.

The spraying is done by a series of nozzles placed at the back of the machine and near to the road surface. The pump is in a recess at the rear of the machine, and it is worked from the rear wheels of the tank. By this means the pump only works when the machine is travelling. A clutch is placed on the shaft, by which means the working of the pump can be thrown in or out of gear.

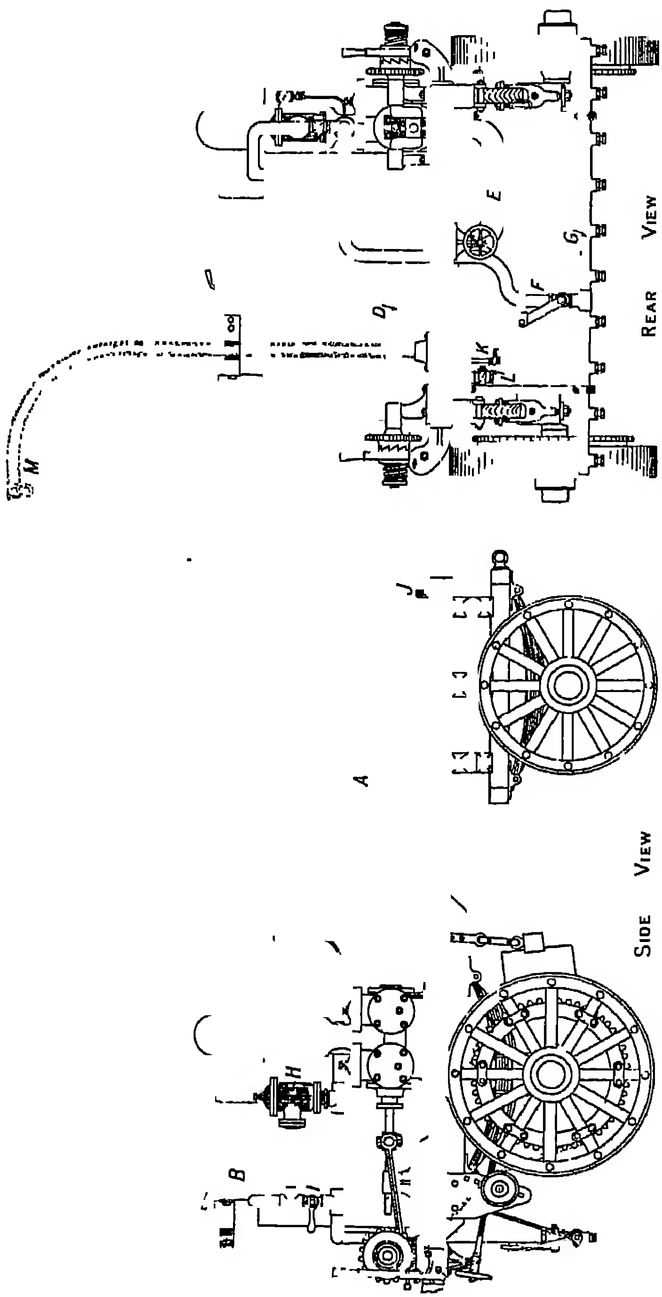


FIG. 24A.—1000-gallon tar-spraying machine.

The spraying can be adjusted to cover from 3 yards to 14 yards per lon of tar.

Spraying with Thick Tar.—The thicker the tar, the more it has to heated to get it of the proper attenuated consistency to be broken into a spray; greater pressure is also required to deal with it satistorily, but it is the rule that, where a heavy tar is used, tar-painting means of brushes is adopted.

Consistency Tests for Tar.—Some distillers distinguish the different alities of tar by specific gravity, but this does not give one any idea whether the tar is liquid or not. The specific gravity may be, say, in one case, whereas another tar of the same specific gravity would ›w quite a different consistency; one might be liquid and the other id.

Twaddell's Measure.—For liquid tars *Twaddell's Measure* is used; s is a weighted glass tube and bulb, which sinks into the tar, the pth that the tube sinks being read off on the tube at the surface of liquid *E.g.* if a liquid tar gives a measure of 40, then the specific ıvity is obtained by multiplying by 5 and adding 1000, then dividing result by 1000—

$$\text{Sp. gr.} = \frac{(40 \times 5) + 1000}{1000} = 1{\cdot}2.$$

The fractionation tests that are given in the British Engineering andards Specification are an ample and sufficient guide to the various alities of pitch and tar used in road construction, and if adhered the results on various roads may be compared.

Combination of Pitch and Oil.—The method of mixing pitch and oil the above-mentioned specification is termed "softening back" or cutting back." It is the method that is adopted to free the tar from e naphthalene. The pitch must first be heated and melted and kept nstantly stirred, so that it is not burned; when the lumps have dislved, the oil is added, and the temperature kept at about 270° F. ıtil all bubbles have disappeared and the surface is perfectly level d glassy. The heating will be performed in a more satisfactory anner if the direct heat from the fire is kept away from the bottom of e pan; the flame should be passed along a flue of brickwork, so that ly the hot gases from the fire surround the pot before they go to the imney.

No definite amount of oil can be given, as the consistency is variable ıd the results to be obtained are not common. A free-flowing conıtency can absorb 30 to 40 per cent., whereas a tar that is pliable when ıld would require only about 16 to 18 per cent. It may be necessary,

if the mixture has been over a fire for a long period, to test the consistency and add more oil. When the mixture is cold and a piece is stretched there should be no small excrescences in the stretched piece, which would indicate indifferent heating and mixing.

Air-tight Covers—Mechanical Mixing.—Where *mechanical mixing* is employed it may be of advantage to use air-tight covers to the pan, but it does not appear to be desirable otherwise. There is too great a tendency to be careless and overheat, and so burn the tar. A good design of pitch boiler is shown in fig. 25.

Failure of Tar.—Many engineers regard tar as a failure, because it has failed in places where it was expected to give success; in these

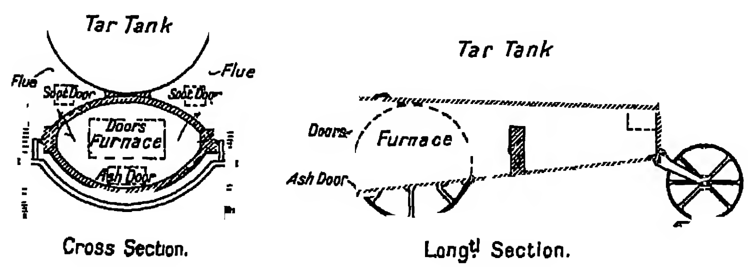


Fig. 25.

cases the fault lies, not necessarily with the material, but in the use of it, the traffic being too heavy for the method of construction.

Where the traffic is light and not too continuous, tar macadam, even when refined tar is used as the binding agent, will last satisfactorily for many years, and an occasional surface dressing of tar, or preferably a mixture of tar and bitumen, or, even better still, a coating of bitumen properly prepared, will give it quite a permanent and lasting surface. It is very difficult to paint a road surface with a thick native bitumen even in a hot state, because it does not adhere to the surface; it will in most cases peel off; the impalpable powder on the surface prevents the adhesion which is necessary.

Mechanical Mixers of Coated Material.—The mixers generally available are for mixing even-sized stone; they are not capable of mixing the fine material which is frequently necessary in some of the compositions that latterly are becoming recognised as necessary to the structure.

The majority have been merely adapted from concrete mixers, and are not suitable for mixing a heavy liquid such as the tar compositions that are being used together with the proportion of fine material that is necessary to fill the voids in the macadam.

The type of mixer should be of the class that has a series of blades on one arm with another arm fitted with a similar series of blades. Each arm would revolve horizontally in opposite directions, thus thoroughly separating and mixing every particle equally. The speed is high, and each batch would be perfectly coated and mixed in less than one minute. The advantage of these mixers lies in the fact that not only will the fine material be equally as well coated with a thick bitumen or tar, but the machine is equally capable of mixing large material, so that it is probable that the batch mixers that are sold for mixing of tar macadam will go out of use, and the revolving arm type will become more in demand.

Cases in which Tar can be used successfully.—The writer is of the opinion that tar should only be used where it can be removed from the effects of the atmospheric conditions. A tar macadam can be made of similar composition to the present macadam, with tar made by a "softening back" of pitch and anthracene oil or creosote oil in the proportion of about 75 per cent. and 25 per cent., the stone and fine material to be made bone-dry by being heated for some time at a temperature of at least 250° F., mixed together in the hot condition, and laid at once on the road, so that when it is cold it is in a solid but just resilient condition. When it has been rolled, the surface should be treated (1) by a coating of bitumen and sprinkled with chippings, or (2) by a surface sheet of varying thickness of a bituminous composition, the least thickness being ¾ inch, but increasing with the traffic up to 1½ inches. In this way a tarred base coat can be used to give a foundation and form part of the structure of the surface, and the tar, being hidden away from the atmosphere, should retain the condition in which it was originally laid. Any tar macadam which is presenting a good surface would be immeasurably improved by a coating of native bitumen, the choice of which may be gathered from the details which are given in the next chapter. The reason for such coating is, that properly selected bitumen is not affected to anything like the same degree as tar by the weather, and so the use of bitumen will assist the life of the tar macadam underneath by removing it from the influence of the atmosphere.

It would be advisable to consider, by a series of analyses of traffic and forms of tar-macadam constructions, for what class of road as regards traffic such tar macadam can advantageously be used, without

breaking up before the material composing the greater part of the structure has had the opportunity to wear.

Satisfactory Sign in a Road.—The most important sign of satisfaction on any road surface is the ability of the surface to become dry after a rainstorm or in moist weather. If a road surface takes a long time to dry out, then one may look forward to disintegration at an early period.

The advantage of a quickly-drying surface is in the winter, as there is less fear of a slippery face due to freezing of the moisture, and also less opportunity for the traffic to beat the moisture into the surface material.

Asphalt disposes of the water most rapidly; new wood paving is somewhat behind asphalt in this respect, and old wood paving is still slower. New tar macadam is fairly rapid in disposing of the moisture, but in course of a little time there are dark patches where the traffic concentrates, which takes a considerable period to disappear. Ordinary macadam is, of course, the longest of any of them.

Nomenclature of Tars and Bitumen, etc.—The Engineering Standards Committee in April 1916 published the report on "British Standard Nomenclature of Tars, Pitches, Bitumens, and Asphalts when used for Road Purposes, and British Standards Specifications for Tar and Pitch for Road Purposes."

1. *Tar.*—Tar is the matter (freed from water) condensed from the volatile products of the destructive distillation of hydrocarbon matter, whether this be contained in coal, wood, peat, oil, etc.

2. *Prefix denoting Source of Origin or Method of Production.*—A prefix such as coal, wood, peat, gasworks, blast furnace, coke oven, etc., must be added to the word "tar" to indicate the source of origin or method of production.

3. *Definition of Pitch.*—Pitch is the solid or semi-solid residue from the partial evaporation of tar.

4. *Definition of Bitumen.*—Bitumen is a generic term for a group of hydrocarbon products soluble in carbon disulphide which either occur in nature or are obtained by the evaporating asphaltic oils. The term shall not include residues from paraffin oils or coal-tar products. The commercial materials may be described as bitumen if they contain not less than 98 per cent. of pure bitumen as defined above.

5. *Definition of Native Bitumen.*—Native bitumen is bitumen found in nature carrying in suspension a variable proportion of mineral matter. The term "native bitumen" shall not be applied to the residuals from the distillation of asphaltic oils.

6. *Definition of Asphalt.*—Asphalt is a road material consisting of a mixture of bitumen and finely graded mineral matter. The mineral

matter may range from an impalpable powder up to material of such a size as will pass through a sieve having square holes of $\frac{1}{4}$ inch size.

7. *Definition of Native or Rock Asphalt.*—Native or rock asphalt is a rock which has been impregnated by nature with bitumen.

8. *Prefixes denoting Source of Origin.*—The Committee recommend that, for convenience of identification, prefixes denoting geographically the source of origin should be attached to each of the four terms defined above.

Petrolenes and Asphaltenes.—The solubility and insolubility in petroleum naphtha is of some importance. The soluble component is classed as petrolenes, the insoluble component as asphaltenes. One is a liquid and the other solid. The petrolenes play an important part in road-structure requirements. The asphaltenes have no binding properties, but when in solution or mixed with petrolenes it is the asphaltenes that give the petrolenes their binding properties and add stability.

If the petrolenes are of a sticky nature and not oily, the bitumen will act as a good cement, whereas the oily variety has not the necessary adhesive characteristics.

Many of the petroleum residues which are classed as bitumens have the petrolenes of the oily kind, and although they may be in ample percentages, they do not provide the proper values which are necessary in road structures.

Asphaltic oils from Trinidad, California, and Mexico are of a sticky or cementitious character, and the proportion of asphaltenes is about $\frac{1}{4}$ to $\frac{1}{5}$ of the petrolenes, hence they are likely to be made into useful asphalt cements suitable for road-constructional work in what are known as bituminous pavements.

Tests.—Tests should therefore be made to determine the specific gravity of the material, its solubility in petroleum naphtha, the amount of paraffin scale it contains, its ductility, the percentage of asphaltenes, its consistency as denoted by a penetrometer, its viscosity which is determined by the rate at which the material will flow at a definite temperature in a given period of time, and its volatility when exposed for a given length of time at a specified temperature.

No Definite Standard.—Although no definite standard has been arrived at, it has been customary to make the comparison with the analysis of Trinidad Lake bitumen, which seems to have provided such satisfactory results that the engineer will not go far wrong if the characteristics closely approximate to those exhibited by this material.

In the future it will probably be determined exactly how far variations may be allowed in the bitumens to be used in this class of work. Some attempts have already been made, and it has been suggested that these should not be less than 15 per cent. of asphaltenes, and that any less than 70 per cent. of petrolenes indicates an insufficiently adhesive material, and these petrolenes must be of the sticky variety.

Nature of Bituminous Material.—It is not the purpose here to enter into a close study as to the nature of bitumens or to what class of hydrocarbons they belong. Information on these points can easily be obtained from the various treatises that have been published by expert chemists.

But it is necessary to indicate the tests which are accepted as being of value to those who propose to use bitumen in road-constructional works.

Even with a bitumen that satisfies these tests, it does not follow that the material will prove satisfactory; the best bitumen in existence can be rendered valueless by carelessness or by an indifferent knowledge of how to use it

Fluxing Oils.—From the previous chapter, the analyses of tar show that there are substances in the tar which are attacked by water and are highly volatilisable at low temperatures, and it is difficult to flux a tar-pitch with other oils than those which have been distilled over, in which there would be about 30 to 40 per cent. of material which has great affinity for moisture and forms into a solid at a temperature of about 50° F.

In the treatment of solid bitumens there are two classes of oils suitable for fluxing. These oils, unless carefully examined, may contain deleterious matter, light oils, paraffin scale, cracked products or unsaturated hydrocarbons, which are easily carbonised on heating

Test of Volatilisable Products.—The bitumens should also have eliminated from them any volatilisable products, and this might be regarded as one of the tests—that a seven-hour test at 325° F. should not give a loss of more than 3 per cent., or at 400° F. 6 per cent. It is desirable that this high temperature should be taken, as it is the usual heat for securing a free-flowing liquid for mixing purposes, and any serious loss of oils would naturally unfavourably affect the mixture.

Defects in Tar and Asphalt Pavements.—The defects which are found in tar pavements are to be found in some asphalt pavements, but they take longer to develop; an asphalt pavement must not develop cracks, disintegrate, or scale or shell off, and should not become too wavy. These defects are caused by a variety of factors. *Cracks* can, of course, be the result of an indifferent foundation or base, the use of an unsuitable bitumen, or the use of an unsuitable fluxing oil in a suitable bitumen. *Disintegration* can be caused by an unsuitable bitumen, one that is too hard in cold weather, a lack of quantity of bitumen, or an indifferent choice of material forming the aggregate. *Scaling* may be caused by the inclusion of light oils in the fluxing of the bitumen or in the bitumen itself, and by too severe a compression while being laid. *Waviness* will be caused by the excess of bitumen, or a bitumen that softens too freely in warm weather.

Tests for Bitumen.—It is therefore necessary that in any bituminous pavement great care should be exercised to see that a stable bitumen is used which responds to tests set forth in the following notes, and which will in some measure be dependent on the aggregate and fine material that is used.

No bitumen that contains paraffin can be termed an asphaltic
ımen, and it will prove to be the case that the residual oils from this
rce will not have much success in road construction, as they are too
rt and have a tendency to emulsify with moisture.

Coal is a pyro-bitumen, *i.e.* it has to be subjected to destructive
illation before the products are soluble in any of the reagents for
ımen, such as carbon disulphide, etc. The product tar is, however,
rectly and properly termed a bitumen.

Mr Clifford Richardson, in his work on *The Modern Asphalt Pave-nt,* lays it down as a guiding rule that an asphaltic bituminous
terial intended to be used as a binding agent in road-paving con-
uctions shall have a melting-point near to that of boiling water, shall
equally soluble in carbon disulphide and carbon tetrachloride, and also
ırge proportion of the bitumen shall be soluble in 88° naphtha. The
lrocarbons soluble in 88° naphtha shall also consist to a considerable
gree of saturated hydrocarbons yielding about 15 per cent. of fixed
bon and a high percentage of sulphur.

The conditions laid down here are being accepted in various parts
the United States, and would seem to give results which are satis-
tory; but they must, like all other tests, only be considered as arbitrary
til further experience has definitely made them or others empirical.
e first of these conditions is important, because if the *melting-point*
high, it shows greater difficulty in dealing with it from a commercial
ınt of view, and when used in a road there might be conceivably a
t easy task in the repair, or even in the laying down, of the material
the first instance. It would also indicate hardness, shortness, and
n-ductility, and in cold weather would probably make a slippery
vement. It may be taken for granted, also, that the percentage of
ed carbon will be high.

A selection of bitumens have been taken, and a comparison will
ɔw their differences :—

Bermudez . . .	Flowing-point		170° F.
Cuban Bejucal . .	,,	,,	240° ,,
Maracaibo . . .	,,	,,	210° ,,
Trinidad Lake . .	,,	,,	190° ,,

ıe percentage of fixed carbon in these bitumens is :—

Bermudez . .	Fixed	carbon	14	per cent.
Cuban Bejucal .	,,	,,	25	,,
Maracaibo . .	,,	,,	18	,,
Trinidad Lake .	,,	,,	11	,,

From these figures, Bermudez and Trinidad Lake bitumen fulfil the requirements laid down, and in this respect should prove more valuable than Cuban or Maracaibo.

The crude bitumen as it comes from the earth has extraneous matter in its composition, such as moisture, vegetable refuse, etc. These must be removed by a process of heating before it is marketable, and it is in this refined condition that the examination is being considered. The solid bitumens that are used in paving work as they are refined are not of the right consistency, but have to be fluxed with lighter oils, and the ease with which this can be done, and the less the quantity required, will also be an important item. Therefore the *softness of the bitumen* may be considered to be a factor, although not one on which too much emphasis must be laid. 0 denotes hardness, and the increase in the numeral denotes a greater degree of softness :—

		Softness.
Bermudez	is represented by . . .	22
Cuban Bejucal	„ „	0
Maracaibo	„ „ . .	20
Trinidad Lake	„ „	7.

This test for softness is not very satisfactory as a guide, because it must be evident that the presence, for example, of the exceedingly fine mineral matter in Trinidad Lake bitumen will have the effect of hardening the bitumen by penetrometer tests. If, however, the mineral matter was removed from the crude or *epuré* bitumen, the softness would be represented by a much higher figure.

The amount of bitumen *soluble in carbon disulphide* is :—

	Bitumen soluble in Carbon Disulphide.
Bermudez	96 per cent.
Cuban Bejucal	75 „
Maracaibo	96·8 „
Trinidad Lake	56·5 „

From a comparison of these two sets of figures, one would conclude that Bermudez and Maracaibo gave better results than the others, and that the softness is dependent on the percentage of bitumen ; the latter would, however, be a misleading conclusion, as will be seen by comparing the " softness " of grahamite on page 132, which is soluble in carbon disulphide to the extent of 98 per cent. Incidentally it shows that the bitumens in grahamite and Cuban Bejucal are different in composition from the remaining three under consideration. With regard to the former conclusion, we have to take another condition, *i e.*

that the bitumen be equally *soluble in carbon tetrachloride.* The analyses show :—

	Bitumen soluble in Carbon Tetrachloride.		
Bermudez . . .	95 per cent	= −	1
Cuban Bejucal . .	76·7 ,,	= +	1·7
Maracaibo .	79 3 ,,	= −	17·5
Trinidad Lake . .	57·8 ,,	= +	1·3

From which we may gather that Maracaibo bitumen has been subjected to abnormal conditions and may prove erratic in any road-paving work.

The percentage of *saturated hydrocarbons* is a criterion of the stable character of bitumen, and is found by treating the bitumen with 88° naphtha and treating the solution with hydrosulphuric acid, the one giving the "petrolenes" contents and the other the "asphaltenes" contents.

	Soluble in 88° Naphtha.
Bermudez	71·9 per cent.
Cuban Bejucal . . .	43·1 ,,
Maracaibo . .	47·2 ,,
Trinidad Lake . .	62 ,,

Here again Bermudez and Trinidad Lake only come within the conditions, although Maracaibo also shows a good percentage of saturated hydrocarbons, which is an indication of the stability of the material.

	Saturated Hydrocarbons.
Bermudez	24 per cent.
Cuban Bejucal	17 ,,
Maracaibo	25 ,,
Trinidad Lake . .	24 ,,

Critically examining the whole of the analyses on pages 128 to 130, Bermudez and Trinidad Lake bitumens fulfil the conditions satisfactorily. Maracaibo and Cuban Bejucal would probably prove erratic, and the latter difficult to work on account of its hardness and high melting-point.

The amount of *mineral matter in the bitumens* will play a very important part in the selection of a bitumen. The analyses give :—

	Mineral Matter.
Bermudez	2·5 per cent.
Cuban Bejucal	21·0 ,,
Maracaibo	1·4 ,,
Trinidad Lake . . .	38·0 ,,

The amount in Bermudez and Maracaibo is so small that it may be ignored. But in Cuban Bejucal and Trinidad Lake it is of importance, and must be carefully examined. The mineral matter in Cuban Bejucal is of comparatively large size, very fine grit, or of a much larger size than in the Trinidad Lake, and the disadvantage is that in heating to a high temperature for fluxing purposes, this grit can only with the greatest difficulty be kept in its place, the specific gravity of the mineral matter (silica) being much higher than that of the bitumen.

The mineral matter in Trinidad Lake bitumen is of an exceedingly fine character, in so much that

90	per cent.	will	pass a	200	mesh.
8	,,	,,	,,	100	,,
2	,,	,,	,,	80	,,

A better idea of the fineness will be obtained from the fact that a proportion of the mineral matter will pass through the filter paper when the bitumen is dissolved in carbon disulphide, so that it becomes difficult to analyse the actual quantity in the mass. It is found by examination that the mineral matter is quartz, clay, and residue of the salts from the mineral water originally emulsified with the crude bitumen. It is intimately mixed with the bitumen, so that if at any time an analysis is taken of this bitumen wherever it had been used, it would be found to contain the same proportions, and it thus becomes a distinguishing feature of considerable value. It is therefore the most perfect form of filler, *i.e.* it forms a medium for using the bitumen to its greatest advantage—whereas in other purer bitumens this advantage has to be gained by artificial means which are difficult to obtain effectively. Further notes on this charateristic are given on pages 145 to 148.

Trinidad Lake bitumen can, therefore, be handled with less care, comparatively, than other bitumens, and with greater certainty in regard to the results, which is of some advantage to the road engineer.

Apart from these analyses, Bermudez bitumen is somewhat variable in composition, as it contains more light oils (9·5 per cent. loss at 400° F. in seven hours), and would therefore harden more rapidly. It has only been used experimentally in this country, but it has been used successfully in the United States.

Maracaibo has not been used at all in England.

Cuban Bejucal, so far as the writer is aware, has also not been used here, but a Cuban bitumen has recently been put on the market, and trial lengths have been laid. Time will prove whether it is likely to withstand successfully the climatic and traffic conditions that prevail.

Trinidad Lake bitumen has been successfully used in roadway con-

struction during the past fifteen years, and although the results were in its early stages of use not very encouraging, its success has been undoubtedly due to a full and complete knowledge of its qualities, to the proper fluxing of the bitumen, and to the care that is exercised in the quantities and disposition in the aggregate with which it is mixed.

Non-asphaltic Bitumens.—There are also other native bitumens than those which have been enumerated, but which are not asphaltic, as will be gathered from an examination of the analyses which follow. Some of them have been tried in pavements, but have not proved consistently successful.

Grahamite—

Softness, 0°.

Bitumen soluble in CS_2	98 per cent.
,, ,, naphtha 88°	·4 to 3·37 ,,
,, insoluble in CCl_4	68·7 to 55 ,,
Fixed carbon	53 to 41 ,,

A very hard bitumen which has passed through high temperature.

Egyptian Glance Pitch—

Softness, 0°.

Bitumen soluble in CS_2	99·7 per cent.
,, ,, naphtha	23·6 ,,
,, insoluble in CCl_4	0·1 ,,
Fixed carbon	15 ,,
Saturated hydrocarbons	6·6 ,,
Melting-point	250° F.

Barbadoes Manjak—

Softness, 0°.

Bitumen soluble in CS_2	99·2 per cent.
,, ,, naphtha 88°	27·0 ,,
,, insoluble in CCl_4	1·2 ,,
Fixed carbon	25 ,,
Saturated hydrocarbons	6·7 ,,
Melting-point	230° F.

Both these bitumens are very hard, having high melting-points. The amount soluble in the naphtha and the amount of saturated hydrocarbons are very low. The manjak has been through a severer temperature than the glance pitch.

It must be emphasised, however, that as the tests are arbitrary, it is quite possible that with a combination of suitable asphaltic mediums these bitumens might be made into useful binding agents for road construction, but considerable skill and expert knowledge would be required to bring them to this state, as has been the case with the bitumens that are now successful, and that have already been mentioned.

Residual Oils.—During the recent enthusiasm for oil for power and light purposes there has been a desire to bring into use the residual oils and pitches.

Petroleum in its crude state contains both heavy and light oils, the latter being removed by distillation or separation from the heavier oils, and if the distillation is taken far enough the residue is a solid bitumen, the procedure being somewhat similar to the treatment of crude tar, when pitch becomes the residue; and the residual bitumen so formed may have no greater value than the pitch, as it depends largely on the manner in which the oil has been treated. The pitch from coal tar can be easily decomposed; so also the residual pitch can be cracked or decomposed. The residuals are sometimes used as fluxes for the bitumens, but the most careful and exhaustive examination has to be made before they can be satisfactorily used. It is at the refiners', as at the gasworks, that the lighter material finds a ready market, and the bitumen is a secondary consideration The process of refining continually has this object in view, and this has been exemplified in two cases at least in a period of six months, as material has been submitted to the writer, and subsequent samples from the same source distinctly differed from the original both in consistency and component parts. Therefore the analyses that are given below are not necessarily the analyses of the residuals from the same source to-day.

Residual Pitch, Texas Petroleum (1907)—

Softness, 18°.

Flowing-point	164° F.
Bitumen soluble in CS_2	98·2 per cent.
,, ,, naphtha 88°	69·6 ,,
Saturated hydrocarbons	65·6 ,,
Insoluble in CCl_4	14·6 ,,
Fixed carbon	19·5 ,,

The above figures indicate that the oil has undergone severe treatment, the amount insoluble in CCl_4, and the amount of fixed carbon, being both high.

Baku Pitch—

Softness, 10°.

Flowing-point	150° F.
Bitumen soluble in CS_2	91·6 per cent.
,, ,, naphtha 88°	54·6 ,,
Saturated hydrocarbons	33·3 ,,
Insoluble in CCl_4	10·4 ,,
Fixed carbon	26·8 ,,

Ebano Pitch, Mexico, is in various grades—

Softness varies between	62 and 7.			
Flowing-point	163° and 278° F.			
Bitumen soluble in CS_2	99·4 per cent. and 95·8 per cent.			
,, ,, naphtha	69	,,	to 48·1	,,
,, insoluble in CCl_4	·4	,,	,, 19·7	,,
Saturated hydrocarbons	7	,,	,, 4	,,
Fixed carbon	19·2	,,	,, 30·5	,,

The fact that there is in the Ebano asphalt a small proportion of satu rated hydrocarbons would give the impression that the material is not o a particularly stable character, and that considerable care would have t(be exercised in using it. There is also a small proportion of paraffin scale

Mexphalte.—This is a proprietary name given to a bitumen whicl is an oil residual and has been standardised. The analysis is suppliec as follows :—

Flowing-point	175° F.
Fixed carbon	18 per cent.
Softness	40 to 50, av. 45
Soluble in carbon bisulphide	99·9 per cent.
,, carbon tetrachloride	99 9 ,,
,, 88° naphtha	68 ,,
Percentage of mineral matter	0·05 ,,

Asteophalte.—This is also the proprietary name given to a bitumer which may equally be termed an oil residual; the analysis is suppliec as follows :—

Specific gravity	1·053
Flowing-point of bitumen	135° F.
Softness	40 to 60
Solubility in carbon bisulphide	99 2 per cent.
,, carbon tetrachloride	99·2 ,,
,, naphtha 88°	70 ,,
Percentage of mineral matter	0·8 ,,

These two bitumens, as will be seen from the comparison of their analyses with those of the standard, appear to have the elements required in a bitumen that is to be useful in road structure.

It has been stated for what it is worth that they are from the same source as Trinidad Lake bitumen and Californian bitumen, because the three are obtained from sources which are in a direct line geographically.

The test which must be the determining factor is the manner in which the various bitumens submit to heavy and concentrated traffic on the road itself.

On many occasions opinions have been expressed which amount to a condemnation of a bitumen because the road in which it has been used has failed to sustain the traffic satisfactorily, whereas it has been the case that the road has failed because the grading of the material was at fault. The bitumen may be perfect, but there may be contributory faults; *e g.* it may have been softened too much, or it may have been used in a too hard condition, some will and have failed because the filler dust has not been sufficient, and in other cases where it has been sufficient but not mixed with the bitumen in a manner that spreads it through the bitumen or has not been properly intermingled or covered with the bitumen. These are all causes which should be closely examined.

In many pamphlets that are issued by firms in the asphalt industry there are terms used which may mislead or cause some difficulty in understanding how to make a comparison. The bitumen is sometimes called "asphalt cement," in other cases it is referred to as "refined asphalt" or "prepared bitumen" or "bitumen." All these terms refer to the same class of material for the same work.

If the term is "asphalt cement" or "refined asphalt" or "refined bitumen," they are so called because the bitumen is ready for use in the paving mixture without any flux, as in the case of mexphalte and asteophalte. Generally these have a softening point between 40 and 50, as set out in the analysis and recommended by the firms.

"Asphalt cement" in the case of Trinidad Lake bitumen is the prepared and fluxed bitumen ready for use in a paving mixture, and similarly has a softening point at about the same figure as suggested above.

But in this case there is in the bitumen about 25 per cent. of mineral matter, so that the softness of this bitumen if the mineral matter had been eliminated would be much greater, just as the softness of the other bitumens would be less if 25 per cent. of fine mineral matter had been added to them.

"Refined asphalt" in the case of Trinidad Lake bitumen is known

as *epuré*, and in this state is not necessarily in a condition which may be used direct with an aggregate to form a paving mixture.

The softness of the bitumen by penetrometer is a very important factor in the paving mixture. For light-trafficked roads it may be softer than where the roads are heavily trafficked. In those districts which are subject to high summer temperatures, the softness may be reduced with advantage—in other areas the softness may be increased; this is the reason for the degree of penetration being within a certain range.

Oil residuals may be regarded in much the same manner as pitch from coal tar; they are subject to the requirements of the refiners, they are waste products, and while there are perhaps greater possibilities if subjected to moderate treatment, care should be exercised that they conform to a fixed standard, otherwise they should be treated with suspicion. The probabilities are that the road made from coal-tar pitch would serve equally as well as the road made from these residual oils, and the advantage in the tar-made road would be its much less cost. With the scientific methods that are now being employed in the selection of bitumens for road purposes, there can be little doubt but that in the future there will be brought into use a residual bitumen that will be able to compete fully with the native bitumens.

Fluxes.—It has been stated in an earlier paragraph that the solid native bitumens in their refined state are not in a proper consistency to be used in road construction. This consistency depends on the atmospheric conditions that are general in the district in which it is to be used. A softer bitumen would be suited to a cold climate and a harder consistency to a hot climate. Similarly, the material that is to be treated will give better results with one consistency than another class of material with the same mixture. To flux the bitumen, therefore, requires knowledge of the capacity of the material to be used, and the atmospheric conditions prevailing.

The fluxes are of a heavy asphaltic nature or of a paraffin base. They are difficult to obtain of a regular and consistent character, for the reasons that have been given above. If a heavy asphaltic flux is used, much more is required than if the lighter is employed. Obviously, if a very large proportion of either has to be added, the flux becomes the medium, and the real asphaltic material takes a secondary place. The heavier the flux, also, the harder does it become in cold weather. For this reason the lighter paraffin fluxes, which give a softer bitumen in cold weather, are used. As less quantity is required, and as a rule it is the more expensive material of the two, it is commercially the most economical. The oil that is used depends largely on the characteristics

of the bitumen, and no empirical conditions can be made that would suit all bitumens. The amount of the oil is, of course, dependent on the consistency requred, but it would not be regarded as a good sign if the bitumen required more than 25 to 30 per cent. of the oil to bring it to a soft or pliable condition. The flux may in itself be unsuitable, or the bitumen may have a high melting-point. The oil that is sought for in those classes of bitumens that come within the conditions before mentioned will have a specific gravity between 0 92 and 0·94 The loss on heating for seven hours at 325° F. must not exceed 5 per cent. It should be soluble in 88° naphtha to an extent of 95 per cent. There must not be more than 10 per cent. left when testing for paraffin scale, and not more than 5 per cent. fixed carbon.

Penetration or Viscosity.—In order to judge whether the consistency of a mixture is precisely the same as that of a sample, the prepared bitumen is poured into a fairly deep tin and allowed to cool to a temperature of 60° or 78° F., and is then submitted to a penetration test, which is performed by what is known as a *penetrometer*.

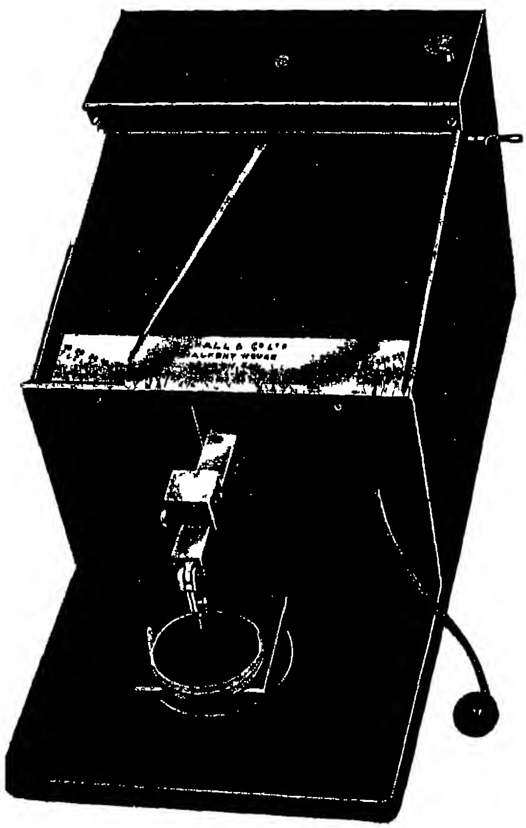
Penetration Machines.—There are various machines which are used for the purpose—one is known as the Bowen penetrometer, another as the Dow penetrometer, and yet another as the New York testing penetrometer. Each of these machines consists of a needle, properly weighted, which is attached to a dial. The needle is brought to the surface of the bitumen, which has been maintained for some time in hot water at the desired temperature. It is then released by means of a spring for a period of 1 or 2 seconds, generally 1 second, and the reading of the penetration is taken from the dial. The Dow and the New York testing laboratory machines practically register the same number of degrees. The Bowen machine registers about 20° higher than the two other machines.

The penetrometer is useful in detecting the amount of surface hardening or oxidation or volatilisation of light oils, or hardening due to molecular condensation.

A tin of the prepared bitumen is tested for consistency by the penetrometer at 77° F. It is then exposed to the air in a position which will ensure it being free from dust. After one, two, and three months' intervals, the penetration is taken again and the difference will indicate the degree of hardening that has taken place in that time. The skin should be peeled off and a new surface exposed; the penetration of the interior should be similar to that taken originally.

A sample of coal tar, pitch, and oil (Road Board's specification) was made so that it had a penetration of 8 mm. at 80° F.; a similar sample of Trinidad Lake bitumen was made with the same

ıt the same temperature, the weight on the needle being he penetration was made by means of a machine designed , so delicately poised that it will distinctly register $\frac{1}{250}$ inch ıe weights on the needle can be varied at the will of the



The Standard Penetrometer.[1]

make a test. The tar or bitumen to be tested is placed in a small he needle, so that it just touches the surface, the pneumatic ball is d the weighted needle is released for ½ second, 1 second, or 2 seconds the dial will then register the depth of the penetration of the liquid, etermine its density or consistency. The test being made at a fixed e, it can thus be readily determined whether the tar or bitumen is of ›nsistency as a previous sample.

ı order to test the two samples comparatively, 4-ounce, 1-ounce weights were employed. The results show that

ırers, B. J. Hall & Co., mathematical instrument makers, 25 Victoria S W.

the pitch and oil mixture differs from the bitumen in a very curious manner; the penetration at 80° with a 4-ounce weight was the same in both cases, but with the 2-ounce weight the penetration was 16 per cent less in the tar composition than in the bitumen, and with the 1-ounce weight was 50 per cent. less. This would indicate that the surface of the tar was harder than the tar immediately beneath the surface, while the bitumen had no surface coat This is also shown by the distance between the lines of penetration, the 2-ounce line being nearer to the 4-ounce than it was to the 1-ounce line, whereas in the bitumen the lines were practically equally distant. When the lines were examined at temperatures below 80° they receded still further, whereas in the bitumen the procedure shows the relation one might expect with an even composition, *i.e.* the lighter the weight the less penetration (proportional) at high temperatures. At 50° F. the penetration of the tar composition was the same as that of the bitumen at about 40° F.

These tests were made several times in order to thoroughly test their accuracy. At 110° F. the penetration of the tar could not be measured, as it was in a freely-flowing condition. The bitumen could, however, show a test both with the 2-ounce weight and the 1-ounce the 4-ounce was too large to measure. The 4-ounce penetrated 24 mm. at 100° F., the 2-ounce at 110° measured 19 mm., and the 1-ounce measured 13·5 mm., so that the bitumen would not flow at a temperature of 110° F., but would easily be squeezed out of shape at that temperature

A test of bitumen had in one case shown—

0·2	mm.	penetration	at	40° F.
0·5	,,	,,	,,	50° F.
3·0	,,	,,	,,	70° F.
4·5	,,	,,	,,	80° F.
7·0	,,	,,	,,	90° F.
12 0	,,	,,	,,	100° F.

But all tests depend on the fluxing oil that is used as well as with the amount—a heavy oil giving a higher penetration at higher temperature, and no penetration at 40°. One would therefore conclude that the lighter oil would be more acceptable in atmospheres similar to that of the British Isles.

From these figures we may naturally infer that bitumen expands and contracts when heat is taken from it or when its temperature is increased. From a test taken by the author, the expansion is regular between 32° F and 212° F., and amounts to one five-hundredth of its bulk for every 10° increase in temperature. This expansion and con-

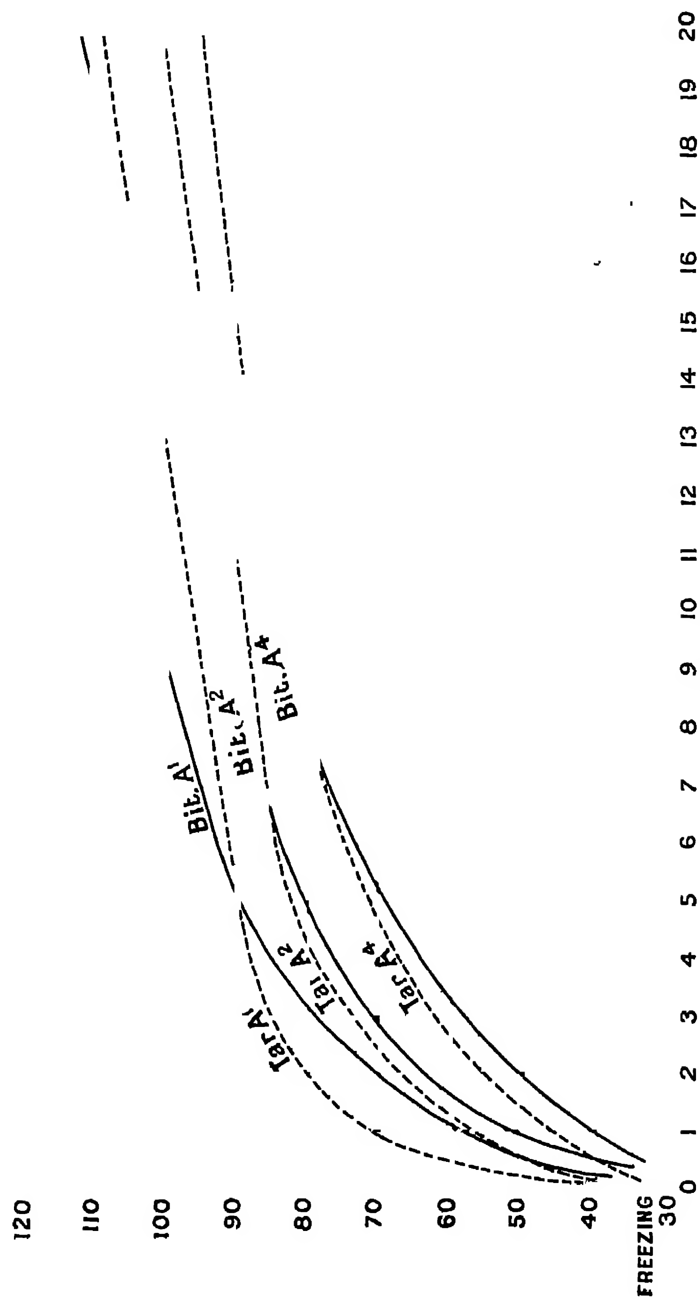

Bit. A¹
Bit. A²
Bit. A⁴
Tar A¹
Tar A²
Tar A⁴
120
110
100
90
80
70
60
50
40
FREEZING 30
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

FIG. 27.

traction will play an important part in the life of the structure in which it is used, and this will be indicated in another and later page of this volume.

It is not a bad sign that the pavement should be soft in the summer, but rather a sign that the nature that has been sought after is still retained in the pavement. A hard and unyielding pavement in the summer would give the impression of loss of life and subsequent disintegration, as it would probably be affected adversely by the continual pounding of horses' feet and the shearing forces of the vehicular traffic. A very high penetration in hot weather and low penetration, if any, in cold weather would prove inconvenient in the summer and wear badly in the winter. A mean must be secured that would be particularly applicable to the work to be done.

The difficulties that are met with in analysing various bitumens when fluxed will be apparent from the following table :—

TABLE XXII.

Bitumen.	Flux.	Penetration.	Bitumen sol. in CS_2.	Mineral Matter.	Fixed Carbon.	Bitumen sol. in Naphtha.
Trinidad Lake . .	23·5	60	66·1	20·2	8·8	47·2
Cuban Bejucal . .	50·0	60	70·0	23·5	11·1	50·7
Bermudez . .	14·0	60	95·5	2·0	12·4	71·0
Trinidad Lake . .	..	7	56·5	36·5	10·8	35·6
Cuban Bejucal . .	..	0	75·0	21·4	25·0	32·4
Bermudez . .	..	26	98·0	2·0	14·0	60·1

Thus, from a limited analysis with a suitable flux, Cuban Bejucal can be made to appear similar to Trinidad Lake. By taking the analysis further, however, the melting-point would at once indicate a difference, and the class of mineral matter in the bitumen would equally distinguish the one from the other. The penetration at various temperatures will also be a distinguishing feature.

Natural and Oil Asphalts.—In a paper, however, written by Mr E. C. Pailler, Department of Public Works, borough of Manhattan, N.Y. City, published by the *Journal of Industrial and Engineering Chemistry* in April 1914, the differentiation of natural and oil asphalts is discussed.

He takes four examples, showing the average, minimum, and maximum amounts found :—

TABLE XXIII.

Bitumen.	Fixed Carbon. Average.	Maximum.	Minimum.	Mineral Matter. Average.	Maximum.	Minimum.
Trinidad	10 20	10 60	0·80	36·00	38 00	30·00
Bermudez	12·90	13·50	12 50	4·00	5·00	3·00
California	14 50	16·00	13·80	0 15	0 20	Trace
Mexican	15·50	18·00	13·50	0·20	0·30	"

The sulphur contents were as follows :—

Trinidad	4·35
Bermudez	5 to 6
California	less than 2·00
Mexican	4·00

which indicates that from the sulphur test it would be difficult to d tinguish them.

He therefore took into consideration a statement made by I. Marcu son that in all natural asphalts there are present a number of organ acids or acid salts, which on distilling are collected in the first few c. of the distillate, and this disillate also contains a certain amount saponifiable oils.

Thirty grms. of bitumen are placed in a retort and heated un it melts ; the flame is raised until the first drop distils, and so adjust that one drop in two seconds is collected. The distillate is collected the weighing tubes in 5 c.c. portions and kept separate. After weighi the tubes with the oil, each of the distillates is dissolved in 10 c.c. portio of ether. The ethereal solution is then washed with water in a separato funnel until free from mineral acids which may be present, transferr to the Erlenmeyer flask diluted with 75 c.c. neutral alcohol ; 5 c.c. of t alkaline blue solution are added and titrated until the red colour chang to blue. The acid number is expressed in milligrams of KOH used neutralise the acid in 1 grm. of oil distillate. Table XXIV. shows t results :—

TABLE XXIV.

Brand of Asphalt.	Acid Value. Distillate 1.	Distillate 2.
1. Pure Trinidad	16·20	8 40
2. " "	15·70	7·00
3. " Bermudez	9·80	3·20
4. " "	9 60	3 60
5. " California	0 11	0·07
6. " "	0·19	0 04
7. Maltha flux	0 12	0 25
8. " "	0·16	0·19
9. Bermudez maltha	9·80	2·30
10. Mexican	0·24	0·05
11. "	0·22	0 09
12. Bermudez+California	4·90	1·20
13. " +Mexican	5·40	2·00
14. " +California+maltha	5·50	1·70
15. " +Mexican+maltha	5·15	1·22

From which we may say that if the acid value falls below 1, we are dealing with an oil asphalt. If we deal with an asphaltic cement which will be shown by taking the penetration, ductility and other physical tests, we should expect an acid value of not less than what is given under No. 9. If it is lower we can expect to deal with a mixture.

Saponification Test.—For the saponification test: 5 grms. of ash-free bitumen are dissolved in 30 c.c. benzol; this is boiled with 50 c.c. N alcoholic KOH under a reflex condenser. After cooling to room temperature 250 c.c. 95 per cent. alcohol are added and the excess of alkali titrated back with NH_2SO_4, using alkaline blue as an indicator. The end reaction is, in spite of the dark colour of the solution, very distinct. The flask is now heated again on the water bath and more acid added if the red colour reappears. This is to be kept up until the colour remains blue. A blank determination is run alongside on the reagents used to make allowance for the action of the alkali on the glass.

Bitumen.	Sapon. No.
Trinidad	40
Bermudez	28
California	12
Mexican	10·5
Maltha flux	8
Bermudez and California, 1 : 1	20·5
Trinidad and California, 1 : 1	26·0
Bermudez and Mexican, 1 : 1	19·7
Trinidad and Mexican, 1 : 1	24·9

The above shows very clearly the great difference between natural and oil asphalts.

In conjunction the two tests with other tests will show conclusively the nature of the asphalt and mixture of bitumens. Further, if the flux is known, a mixture of oil and natural asphalts can be readily recognised as follows :—

TABLE XXV.

	Fixed Carbon.	Mineral Matter.	Acid Value.		Sapon. Value	Conclusion as to Nature of Bitumen.
			1st	2nd.		
	per cent.	per cent				
1	12·30	4·90	9·6	3 6	29·8	Bermudez
2	9·95	35·60	15 9	8 1	36 0	Trinidad
3	15·85	Trace	0·16	0 08	11·2	California
4	10·10	,,	0·12	0·18	7 4	Maltha, California
5	14·60	2·21	4·0	1·2	19·3	Bermudez, 1 : 1.
6	14·15	2·94	4·7	0·9	22·0	California and Bermudez, 3 : 7
7	16·87	0·20	0·24	0·05	9·8	Mexican
8	17·24	0·22	0·22	0·09	10·7	,,

Apparent Weakness of Tar and Bitumen.—Having in this and the previous chapter dealt with the composition of both tar and bitumen, emphasising the apparent weaknesses so far as one is able to judge with present knowledge, it is perhaps desirable to point out that there seems to be a possibility that what are to us to-day thought to be defects, may with future knowledge not be defects, or even if they are, then by manipulation they may be usefully employed.

One of the reasons for these remarks is that when the bitumen is solved out of the refined Trinidad bitumen it is, when so obtained, in bulk a comparatively speaking plastic substance, not brittle, and somewhat similar to other bitumens from a physical point of view that are manufactured, or what may be called residual bitumens.

Colloids.—It has been contended that the satisfaction that Trinidad bitumen gives in road structures is due, naturally, to the bitumen, but more particularly to the fact that it contains a considerable quantity of exceedingly fine material which are technically called "colloids." The grading of the mineral matter in this bitumen has already been given down to the 200 mesh, but there is a quantity much finer than material that will pass the 200 mesh ; it is so fine that it passes through the filter paper and can only be obtained by allowing the liquid to stand for about forty-eight hours. Even then there is fine material in the bitumen, and this cannot be secured by any of the ordinary methods ; but undoubtedly it plays an important part in the use of the bitumen for road structures.

A pound of filler dust has been estimated to contain 192,715,475,500

icles, having a surface area of 527,821 square feet, while a pound of nary sand is estimated to contain 129,030,065 particles, having a ace area of 44,378 square feet to which the bitumen may adhere. ucing a ¼-inch cube to particles of colloidal size is estimated to ease the surface area about 100,000 times. Colloids are in such ely divided condition that when suspended in a liquid they do not e out, but remain suspended indefinitely; it is stated that under the -microscope there can be seen in active motion in Trinidad bitumen ons of particles not more than 0·0000393 inch in diameter.

Surface Energy. This fine material in the bitumen is supposed to greater surface energy, which is illustrated in an example. If two s of glass with perfectly flat surfaces are brought together, it is ult to separate them owing to the surface energy of a film of air or d between them. Similarly the fine particles hold the bitumen as m about themselves, and therefore a bitumen which either contains fine material in a natural state or where it is artificially added, will e to have more stability than that of other bitumens not so provided. further illustration of this effect is observed in the testing of samples ituminous mixtures. If small pieces of natural asphalt, Trinidad alt, and asphalt made from a residual bitumen are submitted to on disulphide, the natural asphalt and Trinidad asphalt will take t forty-eight hours to free the bitumen from the sample, but in the example it has been done in about half an hour.

Izes of Sands, etc.—Mr Clifford Richardson, in a paper on "The ry of the perfect Sheet-Asphalt Surface," published in the *Journal of strial and Engineering Chemistry*, vol. vii., No. 6, p. 463, June 1915, an example of the number of particles and their surface per lb. ineral aggregates of the type in use in New York in the nineties:—

TABLE XXVI.

h of vo.	Coarse Sand and Dust. Per Cent.	No. of Particles.	Surface. Sq. ft.	Fine Sand and Dust. Per Cent.	No. of Particles.	Surface. Sq. ft.
.	13	12,592	0·958	4	3,074	0·295
.	12	66,186	1·570	7	38,808	0·921
.	10	167,547	1·901	9	150,796	1·715
.	13	664,250	3·503	11	561,868	3·033
.	27	5,021,870	11·470	26	4,835,870	11·054
.	10	4,086,220	5·527	15	6,127,910	8·099
.	7	10,415,700	5·952	15	22,319,400	12·754
.	5	31,924,800	6·000	7	44,694,000	9·072
I m.	3	76,671,400	6·480	6	153,343,000	12·960
	100	129,030,065	44·378	100	232,075,324	60·503

TABLE XXVI.—*continued.*

Size of Particles. Millimetres.	Dust or Filler. Per Cent.	No. of Particles.	Surface. Sq. ft.
0·08 . . .	18·8	120,035,300	25,976
0·05 . . .	17·7	452,300,200	38 231
0·025 . .	51·3	10,732,900,000	226·825
0·0075 . .	5·0	30,775,730,000	58 500
0 0025 .	7·2	150,634,400,000	178·199
	100·0	192,715,475,500	527·821
If all the dust is 0·025 diameter		20,922,050,000	442,157

From which data it appears that the finer aggregate presents a surface area of 60·5 square feet to the lb., and the coarser one but 44·4, a difference of 32·6 per cent. in favour of the finer material. That the greater the increase in area the finer the material grows is demonstrated by the figures given in the last section of the table.

Basis of Perfect Asphalt.—Mr Richardson suggests that the basis for the construction of a perfect asphalt surface lies in a consideration of the chemistry of surfaces and films. In a subsequent paper read before the Western Society of Engineers at Chicago on November 20, 1916, he went further into this matter, and demonstrated the capacity of various bitumens to retain colloids, by introducing colloidal clay to them. The amount may reach with certain oils as much as 60 per cent.

The native bitumens of a highly viscous nature and the heavy residuals derived from asphaltic petroleum possess very different capacities for maintaining clay in suspension in a colloid state. Colloidal clay was introduced into a number of solid residuals of various types of petroleum by the addition of enough aqueous clay paste to result in a material which, after the removal of the water, should consist of 67 per cent. bitumen and 33 per cent. clay. These materials were maintained in a melted condition at a temperature of 325° F. in tubes for twenty-four hours. The sedimentation which, with the reduction of the viscosity of the continuous phase, went on for that period appears from the following figures :—

TABLE XXVII.

Source.	Penetration.	Per Cent. Colloidal Matter. Before Heating.	Per Cent. Colloidal Matter. After Heating.	Per Cent. Sedimentation.
Trinidad residual	50	33·5	33·7	0·00
Bababui "	48	32·1	30·1	7·00
Mexican "	50	33·3	27·2	18·30
California "	50	31·8	23·8	25·2
Mid-continental semi-paraffin residual	51	33·8	21·7	35·8

The striking feature is that the residual bitumen prepared from the mid-continental field deposited 35·8 per cent. of the clay at high temperature, showing the small capacity of paraffin oils to maintain clay in suspension in a colloidal state.

As the film of bitumen which covers the mineral aggregate of a sheet-asphalt pavement is formed at the temperature given, these data may convey some idea as to the capacity of the different materials for coating the grains of this aggregate, but too much dependence must not be placed upon them, as there are so many other controlling features in relation to the character of the films.

Importance of Filler Dust.—If the "colloid" theory is to be accepted, and there is apparent justification, then it may be the case that by some system of filling the bitumen with a material of a colloid form that is now free from it, the bitumen so treated may become a much more useful substance in road structures than it is now. It is clear that a study and a series of experiments in this direction may be of great service.

Methods of determining Filler Dust.—The filler or fine dust that should be added to the aggregate should not only pass the 200 mesh, but should, when mixed with water, remain suspended in the water for fifteen seconds, which means that a large proportion should be even less than would pass through the 200-mesh sieve.

It must be remembered also that some bitumens already contain a percentage of this fine material, so that with the use of such bitumens it would not be necessary to provide such an amount as would be the case where the bitumen has no filler at all.

Another method of quickly determining the size of the filler dust is to place the dust in a receptacle and to blow air through it at a certain pressure; by means of a run of U tubes, the various sizes of fine dust can be calculated from the amount deposited in each tube.

Neither of these tests will give an accurate idea of the filler dust, as the specific gravity must have its effect in determining the amount of

fine material that settles through the water in the one case and similarly in the various tubes in the other.

Effect of Filler Dust on Bitumen.—Trinidad bitumen in a refined state has a specific gravity of 1·39, with a melting-point at 230° F. But when the fine material is removed and the pure bitumen is obtained, then the specific gravity is 1·06, and it has a melting-point of about 160° F. This alone indicates the value of the fine material; it obviously must increase the specific gravity, but it also increases the apparent melting-point.

This fine material would therefore be of value to tar processes. There have been numerous instances of pitch grouting where the atmospheric temperature has been such as to cause the pitch to "bleed"; if it had been saturated with fine material it would have been so affected that the pitch could not "bleed." The writer had a very bad case, and purchased a quantity of lime in a powdered state, scarified the road, lightly sprinkled this powder over the road so scarified, and re-rolled the composition. It remained afterwards quite free from "bleeding."

Filler.—The addition of filler or fine dust is, as has been indicated, for the purpose of spreading the bitumen over a large area; too much filler will render the bitumen useless, and too little will have a detrimental effect in rendering the mass too mobile in hot weather. A spot of gum has not its adhesive qualities shown to the best advantage if used in that way, but if that quantity is spread over an area in a thin layer its adhesive properties are placed to greater advantage and the desired results are secured. It is similarly the case with bitumen; if the filler is in correct quantity and in the proper place, it becomes the agent for conveying the prepared bitumen to the proper quarter, and the greatest advantage is obtained for its adhesiveness and ductility.

From what has preceded, it will be gathered that satisfactory results from an economical and from a lasting point of view can only be secured by a careful and deliberate inquiry into the class of bitumen, the nature of the flux, the methods of adding filler, and the amount of bitumen that should be used with a given class of stone.

With regard to the latter item, an illustration may be taken from everyday experience in the mixing of cement concrete. It is well known that a neat cement mixture would prove unavailing in engineering work, and that a mixture of 10 or 15 of sand to 1 of cement would rarely be used with any prospect of success, but the intermediate course of employing 6 of a mixed aggregate to 1 of cement would withstand very considerable strains for long periods. Thus the amount of cement used in the composition depends on the size of the aggregate: with large stone less cement is used, with fine sand more cement is used,

and the intermediate stage of large and fine materials requires an intermediate quantity. The exact quantities are fairly well known.

Bitumen in Concrete.—Equally is it the case with bitumen; it is more satisfactory when it is used as the Portland cement is used in concrete, the amount depending on the quality, quantity, and dimensions of the aggregate. Unlike the cement, not only has it adhesiveness but it should also have, and in most cases has, ductility, and thus gives the concrete in which it has been used the resiliency which is desirable in road construction.

The most important feature about a native bitumen is its consistency in quality; if any paving fails, the cause of the fault is narrowed down to a much finer degree than can be the case with a tar or oil residual.

SUGGESTED SPECIFICATION FOR BITUMEN IN ROAD CONSTRUCTION.

Freedom from Water. Fractionation. The bitumen shall be free from moisture, and on distillation for seven hours at 325° F. should not have a loss of more than 3 per cent. by weight, or a fresh sample distilled at 400° F. for seven hours should not have a loss of more than 5 per cent.

Temperature. The temperature during distillation shall be taken by placing the bulb of the thermometer in the distillate gases of the distillation flask.

Fixed Carbon. The amount of fixed carbon shall not exceed 15 per cent.

Solubility in CS_2. The bituminous cement shall be dissolved in pure carbon disulphide, air temperature, and the deposit shall wholly consist of mineral matter and not more than 4 per cent. of carbonaceous matter, insoluble in chemically pure carbon disulphide.

Solubility in Naphtha 88°. It shall be soluble in naphtha 88°, air temperature, to the extent of not less than 60 per cent. and not more than 75 per cent.

When the above naphtha solution is submitted to strong sulphuric acid, sp. gr. 1·84, it shall leave at least 15 per cent. and not more than 25 per cent. of the bitumen unaffected.

Solubility in CCl_4. It shall be soluble in carbon tetrachloride to the extent of not less than 1½ per cent. less or 1½ per cent. more than the solubility in carbon disulphide.

Paraffin scale. It shall not contain more than 2½ per cent. of paraffin scale.

CHAPTER VIII.

METHODS OF USING TAR AND BITUMEN.

Mixtures of Tar. -The author has employed many mixtures of tar and has found it difficult to bring the tar to any standard with precise additions of other material. The method, however, which has given the most uniform results is to bring the tar to a consistency that at a certain temperature, when submitted to the penetrometer test (p. 137), a definite penetration is measured. For the base mixtures mentioned elsewhere the penetration is 120° at 60° F.

This penetration can be obtained by adding soft pitch, dry-powdered lime, and resin until the so-treated tar gives the necessary consistency. Resin is added because it seems to improve its adhesive qualities, and Trinidad Lake bitumen is also employed. There have been doubts expressed as to the possibility of mixing Trinidad Lake bitumen with tar, but from the tests that have been made for the Road Board in the experiments mentioned later, there is some reason for thinking that the addition of the bitumen has not any deleterious effect on the tar, or *vice versa*. Trinidad Lake bitumen, however, is not added on account of the bitumen contents, but because of the fine material that is incorporated with it. Experiments with tar in which the fine mineral flour is added are apparently equally satisfactory, and of course more economical in cost. The class of flour is mentioned elsewhere; any exceedingly fine dust will serve the purpose, the grading of which can be secured by means of a flourometer. That grading of this fine material is as necessary as the grading of the still fine but coarser material is exemplified by the fact that Portland cement does not give good results as a cement unless the material contains not only a large proportion that passes a 200 mesh, but also that it contains a distinct percentage of material much finer than will pass a 200-mesh sieve.

In bringing tar down to a certain consistency it is clear that the addition of the light oils will give the results required with comparatively

a much smaller quantity than would be given by employing creosote oil, and still less than when employing anthracene oil. It has not been proved which method is the better; probably the heavier oils will give the best results, because of the tendency of the lighter oils to volatilise to a greater extent.

In the opinion of the writer there must be an elimination of the high percentage of naphthalene which is included in a straight-run tar. That tar has not been sufficiently exploited in the direction of the amount of fine material it should contain is unfortunate, but that this examination should be made in the near future is undoubtedly advisable.

Tar Macadam.—The tar macadams that have been said to be a success are in fact only comparative successes. The roads on which they are placed have traffic which cannot properly be considered to be "heavy." In the future, with the evident popularity of the transport of goods by motor vehicles on roads, the intensity of the traffic will be far greater than many engineers anticipate

On examination of the results obtained in many different localities, it will be noticed that the more even the size of the stone employed the greater are the number of failures, and the denser the structure the fewer are the failures. There has been a tendency to eliminate all the fine material from the composition, sometimes because it necessitates such a large amount of tar to coat the material, sometimes because the area covered with the material in which the fine material is noticeable does not extend as far as it was expected.

The addition of 20 per cent. of fine material does not increase the area to be covered, which indicates that the other material with which the comparison was made contained 20 per cent. of voids This is quite possible, as one-sized material gives as a rule 40 to 45 per cent. voids, so that 20 per cent. of finer material could easily be inserted without increasing the volume. Then in other cases it is laid with a coat of fine material to form the surface, but the size of the stone employed is from ¾ down to ¼ inch, all the material passing the ¼-inch screen being removed. It must be obvious that the voids in this composition must be considerable, as the spaces between, say, a series of ¾-inch stones cannot be filled with either ½-inch or ¼-inch material. In a number of trials made by the author the voids are, under the most favourable circumstances with material of this size, at least 30 per cent. Some proportion of these will be filled with the tar coating, but it would not be far from the mark to suggest that the voids would be 25 per cent.

Hence the necessity for applying the tar coating to seal the structure from atmospheric conditions.

Further, if the traffic is heavy and the sealing coat worn, as it must

be under traffic wear, it will leave the structure more easily subject to the weather, which will soon cause with the traffic its disintegration.

In the writer's view, although it is almost impossible to obtain a structure which shall be voidless (it is doubtful whether it is even desirable that it should be voidless), the road structure to be satisfactory should not contain more than 10 per cent. voids.

When a structure contains voids to the extent of 25 to 30 per cent., the stone composing that structure is subjected to severe strains and will fracture and grind and eventually be subjected to a greater compression than was given by the steam-roller that was employed to consolidate it in the first instance. In consequence, one may expect the corrugations which develop on a weak structure more rapidly than a more dense composition.

It is desirable that in any work that is to be carried out and which involves the use of tar, the specification of the British Engineering Standards Committee should be taken, and it should be definitely known whether the tar obtained does actually agree with the specification.

With the use of the tar, care should always be taken that the heating of it in the tar boilers is not overdone, otherwise the effect of the specification will be nullified. It will be seen by an examination and study of the various analyses of distillates, how the tar may be affected by careless heating; it should also be constantly stirred, so that the tar at the bottom of the tar boiler is not burnt.

When tar boils over, it is because the tar contains water.

It is also as well to note here that it is desirable in many cases to add fine dust, as fine as flour, to the tar. Cement is frequently used, but slaked lime is also employed for this purpose. When slaked lime is obtained it is in the form of a fine powder, but notwithstanding its appearance it contains a considerable amount of moisture, and its addition to tar at the tar boiler must be carefully adjusted, otherwise the tar may overflow if the temperature is above 212° F. The moisture must be eliminated by heating, *i.e.* the frothing and bubbles should disappear and the surface be smooth at this temperature.

TAR MACADAM.

Tar macadam is a name that is given to a road structure in which the stones are coated with tar. It is usually composed of stone that will pass through a 2-inch ring, the average stones under this condition having a maximum dimension of 1¾ inches. The stone is heated, but as a rule no temperature is taken; if it looks dry and feels hot, this is usually taken as sufficient. The stone should be passed through a temperature of about 230° F., and allowed to cool down to about 100° F.;

it is then in a condition to be coated with the tar. The tar that is used is the dehydrated tar mentioned in Chapter VI., but there are variations dependent on the experience of the person making the tar macadam. There has been no standard up to recent years, and the tar is sometimes that from one works or from a series of works.

Treatment of Tar.—It is taken to the tanks and there allowed to simmer at a temperature of about 212° F. for some days, is looked after by an "old hand" who syphons off the light oils, moisture, etc., until it is of the right consistency; or the tar may have been passed through an intermittent form of distillation, as suggested in Chapter VI., or from a "continuous" distillation plant, where the tar is converted to pitch and afterwards softened back to the proper consistency as required by the person who is making the tar macadam. The prepared liquid is heated to an attenuated form, *i.e.* to flow freely, and is then poured on to the hot stone, and the two are shovelled together or mixed in a mechanical mixer until all the faces of the stone are properly covered.

The Proportion of Tar to the Stone depends on the quality of the stone and its size; it will be about 6 gallons to the cubic yard of 2-inch stone, and not exceed 10 gallons in any quality.

A second size of stone is similarly treated, and in some cases even a third size is used. Some manufacturers make the second size ¾ inch clean, or ¾ inch to dust; another variation is ½ inch clean, or ½ inch to dust. Others will eliminate the dust or consider the dust to be no smaller than ⅛ inch. This material, in whatever variation, is heated in a similar manner to the large material, and treated with tar; in this case the quantity of tar, as will be anticipated, is increased, and will be approximately about 16 gallons, and even up to 20 gallons per cubic yard. The quantity is gauged by the appearance of the stone when coated; it should not be in so large a quantity that it drips off the stone, nor in so small a quantity that there are areas uncovered.

Material Heaped.—These mixed stones are then wheeled away to a heap and remain exposed to the weather for from one to six months. The bright black appearance of the tarred stone is soon lost, and the stone becomes dull and binds hard on to its neighbour, a pick being used to separate them. However, the under face has not lost much of its vitality, and many hold the view that it is in a better condition after it has been so stored. It is obviously a commercial and economical advantage to be able to mix it and store it, but undoubtedly there must be a hardening going on due to volatilisation, and the actual condition of the tar on the stone must be worse than when it was originally mixed, so that fresh mixed tarred stone should be more satisfactory.

Laying on the Road.—The 2-inch tarred stone is taken to the road and is laid two stones thick on the prepared foundation (fig. 28). This coating will roll to a general thickness of 3 inches, and will leave a very open and porous surface. On the top of this, while it is in a dry condition, a coat of the finer material is then laid to a depth when rolled

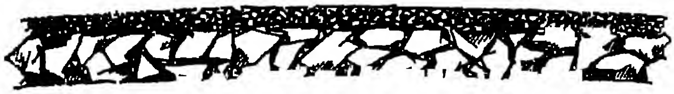


FIG. 28.

of 1½ inches. Frequently the tarred stone has been allowed to remain stacked too long, so that it looses its adhesive qualities and the surface permits moisture to penetrate freely; the surface is therefore coated with hot tar, and fine chippings are sprinkled over it, thus sealing the surface and also giving the required consistency to the tarred material in the surface.

FIG. 29.

Another method (fig. 29) of laying the stone is to spread the large stone as described above, but before it is rolled the finer material is spread on the top of the 2-inch material, and the mixture rolled and fed as required until the mass is apparently homogeneous and presents a closed surface. A tar coating may or may not be used as an adjunct.

FIG. 30.

A third method (fig. 30), not very frequently practised, is to lay the small material first and the larger material on the top of it, rolling the latter until the finer stone surrounds the large material. It is difficult to obtain success with this method unless the tar is somewhat fresh on the stone, and the rolling does not even then make a satisfactory finish.

Although these methods have been tried for many years, the one that is least satisfactory in theory is the most popular, that is, the one first described, and mainly because it gives a fine even surface and there is least trouble in securing results. The second process is better than the first, and is the one from which the writer has obtained the best results. The third process is better in theory than the second, because the finer material should surround the larger stone, both in the bottom and the top, but it is the most difficult to lay, and the results, which are probably due to inferior laying, are not satisfactory.

Mr. Gladwell, the surveyor to the Eton Rural District Council, brought this third method into prominence by using untarred stone on the tarred fine material, and probably more on account of the quality of the tar used than through the use of untarred material, gained some success, because the stones were unable to slide on each other to the same extent that they would where the stones were wholly covered with tar, and with a tar of an indifferent or unstandardised quality. The writer's experience, using the ordinary refined tar, was not encouraging, and this has been the case with others who have endeavoured to adopt the method.

Value of Tar in Road Mixtures.—Undoubtedly it is the case that too little attention has been given to the value of tar for road-making purposes. If the same amount of scientific research had been given to tar as has been given to bitumen, a different report would be given. The placing of a filler in the tar is essential; many engineers are using chalk or lime in a powdered state. Then the structural composition, including the grading, requires consideration; it would enable this material to be more effectively employed than is now the case. Where proprietary tars have been employed and the tar is standardised and treated, there seems to have been more satisfaction given than in those cases where the tar has been taken as supplied from gas companies or distilling works. There is here an indication that it is the treatment and filling of the tar which enables it to be used with a degree of success, as has been indicated elsewhere.

Possibilities in Tar not yet realised.—There are possibilities in tar which are not yet realised, and if sufficient funds were available, and time and areas set apart for a systematic series of experiments, there can be no doubt that tar could be made into a very useful binding agent and take its place more effectively to form an acceptable and useful form of pavement.

Aggregates.—Some engineers have the idea that from their experience there is a virtue in a particular form of aggregate. Some will say that "slag" is far preferable to "granite," others that "limestone"

is better than either slag or granite. There are those who suggest that there is no necessity for fine material or differential grading, that there is no advantage in filling the interstices; while others, equally sincere, have the distinctly opposite opinion. As a matter of fact, there has been no scientific examination which would assist in determining the value of any of these opinions.

Failure of Tar Mixtures.—Failure of tar macadam is due to inappreciation of the essential points of the tar; very often to the careless manner in which the composition is prepared and applied. From the many examples that have come before the writer, they are not as good as would be obtained from the tar-spraying or painting of a well-made water-bound macadam roadway; in fact, there is reason for saying that the latter form is far better than the majority of tar-macadam roadways, because in most cases of tar macadams the success of the road has entirely depended on how the tar macadam has been regularly sprayed or painted with tar or bitumen and the under part sealed from the weather effects. The sealing coat is the wearing surface, and the tarred material is merely a support for the sealing coat, and in all probability the macadam road would have served the same purpose as it has done in many instances.

One-Size Macadam.—In a macadam structure made of one size of stone there is always the same percentage of voids, *i.e.* about 42 per cent. Most of the tar macadams are made of one size, and therefore have at first this percentage of voids. The coating of tar and compression that is given will reduce this quantity to some extent. The principle that is adopted by some is as follows: $1\frac{1}{2}$ inches is used as a base, then $\frac{3}{4}$ inch, then $\frac{1}{4}$ inch as a finished coat. Each of these has the same percentage of voids, and the only part of the process that prevents water from penetrating is the finishing coat of tar which is applied, and may on the small material form a complete seal depending on how heavy is the coat. It is frequently in evidence that a newly laid tar-macadam road shows a wet surface long after the rain has subsided, hence the desirability of using a good sealing coat; but it must be clear that, as soon as the sealing coat is worn away, the understructure will permit the moisture to penetrate, with obvious results.

Graded Mixture.—The principle, therefore, of adopting a properly graded surface mixture is apparent, so that not only shall the voids be reduced to more reasonable limits, but that an impenetrable layer of appreciable depth should be formed to prevent moisture from obtaining access below the surface.

Where bitumen is used successfully with sand and cement, tar has not been so successfully used; but there are possibilities, because the writer in one experiment found, by using a very fine filler with the tar,

it lasted some considerable time under heavy traffic. Unfortunately circumstances arose which prevented these experiments from being carried further. But from the knowledge that was thus gained it was clear that a constituent can be added to tar which will improve its qualities and make it a more useful material in road structures.

Combination of other Materials in Tar.—In connection with these methods of tar macadam, the writer has tried many combinations of tar and pitch with resin and lime, the resin to add to the hardening of the tar, and the lime for the purpose of acting as a filler to the tar and make it a conveying medium. Similarly, a mixture of pitch, creosote oil (or anthracene oil), resin, lime, and Trinidad Lake bitumen has also been tried, and this gives fairly successful results if the mixture is laid shortly after it has been mixed; it will stand heavy traffic for about twelve to eighteen months, after which it begins to ravel or crack and give way. It has therefore been used with the fine material (⅜ inch to ⅛ inch and dust), and laid in the depressions of the water-bound roads; it thus sets quickly, and forms a wearing face level with the other portions of the road not worn, and considerably lengthens the life of the whole of the road. It is satisfactory even when laid about 1 inch thick.

The proportions are :–

Pitch, 66 per cent. } Creosote, 33 " }	81 per cent.
Lime	6 "
Trinidad Lake bitumen	10 "

Also the following proportions give superior results :—

Dehydrated tar	80 per cent.
Resin	1·5 "
Lime	5 "
Pitch	6 "
Trinidad Lake bitumen	7·5 "

In order to prepare the mixture, the pitch is melted, then the creosote is added, afterwards the resin; the lime is sprinkled over the heated mixture, and then the melted bitumen is added.

The reason of such improvement is probably due to the fact that the tar is not severely treated. In order to obtain pitch the tar is taken to 518° F., which is a destructive temperature, and it may prove to be the case that the tar to be used for road purposes should never be taken beyond about 300° F., and that it should be kept at such a temperature

until by volatilisation the desired consistency is obtained: the heating may even have to be taken over a period of days.

Stone used in Tar Macadam.—The stone that is used may be granite, the more porous and dust-making being better than the very impervious and dense varieties. Broken slag from iron and steel works is also popular, and in some districts burnt flints have been found satisfactory. But perhaps limestone is the material which has had a greater vogue than either of the above-mentioned stones, and probably this has been the case because of its greater affinity for the tar.

Tarmac is a proprietary tar macadam. The stone that is used is blast-furnace slag, which is treated before it is cold, and therefore when there can be no moisture in it, when it is said to be in a far better condition for receiving tar than after it is cold. At the works the tar is distilled and prepared with pitch and other ingredients to certain uniform chemical and physical standards, the methods to obtain the best results being adopted, so that this preparation should give satisfaction as far as possible with the material at hand. In this case the tar and the slag are waste products, so that the combination should be exceedingly cheap in first cost. The stone is graded—2¼ inches includes 2¼ inches to 1½ inches, 1½ inches includes 1½ inches to ½ inch, and ⅝ inch includes ⅝ inch to ⅛ inch. These are sent out, the largest being laid in the bottom, the next size on the top of the large material, and the finest material forms the surface.

Tarvia is a specially prepared mixture of pitch, dead oils, etc., and is made in two grades "A" and "B," the "A" grade being a free-flowing liquid under heat, whereas the "B" grade is of a more solid character. The "A" grade is used for tar-painting and spraying of roads, and the "B" composition is used for mixing and coating stone, and acts as the binding agent in road construction.

Quarrite is a proprietary composition of small-sized limestone chippings in various grades, each being coated with tar and mixed together in certain proportions, and rolled to an even face.

There are other variations of tar macadam each differing from the other in a more or less slight degree; each of them are cold processes, *i.e.* the material is brought on to the job at ordinary atmospheric conditions, and whatever "setting" goes on must be due to volatilisation, oxidation, pressure, or a combination of the three.

POURING-IN PROCESSES.

Other forms of preparing tar macadam are known as the "pouring-in" processes or "penetration" methods. They may be described as "hot and cold," to distinguish them from those above described.

The ordinarily broken 2-inch granite macadam is laid two stones thick, *i.e* to 3 inches when rolled to an even surface. This surface will show a large number of interstitial spaces or crevices, into which is poured a mixture of pitch and oil, sand and cement—the oil being that known as sharp oil, creosote oil, or anthracene oil. The specification of a mixture is given in the Engineering Standards Committee's description at the end of this volume. The method adopted is to obtain a bucket partly filled with the heated pitch, then from a quantity of hot sand and cement sufficient is taken to double the volume of the pitch in the bucket; this is stirred vigorously, and while in a stirred condition it is poured into the crevices of the stone.

The process is crude and uncertain, and, left in the hands of an unskilled person, with no means of ascertaining whether the mixture is properly made, there can be no check on the quantity or proportion per superficial yard. In some cases the writer has seen the crevices unfilled and the stones practically untouched, while in other areas the crevices have been filled to the surface. If the spaces are filled the quantity required would be about 4 gallons to the superficial yard, and in this case the mass is a monolith, *i.e.* there are no voids, and the surface in cold weather would be hard, unyielding, non-resilient, and probably very slippery. In very hot weather the pitch is nearly in a flowing condition, and sometimes comes to the surface and finds its way towards the channels.

This softening would in time disappear with the volatilisation that must go on, but it would then be more easily surface-broken. The repair of such a road must be somewhat difficult to manipulate.

This flowing of the pitch can be eliminated by either filling more fine flour into the pitch before it is poured into the crevices or by hardening the pitch, in which latter case the road will present a very hard surface in cold weather.

In the writer's opinion the principle is far superior to the usual methods employed in tar-macadam structures, especially if the grouting could be done with greater accuracy. It is, however, not carried out to its literal extent; the amount of pitch grout employed is varied according, probably, to the cost of the paving that is allowed. In some cases 1 gallon has been allowed, in other cases 2 and 2½ gallons; rarely is the full amount of 4 gallons, which would fill the interstices, employed. Where the composition has been comparatively freely used to the extent of 2½ or more gallons, greater success has attended the experiment than where a limited amount like 1 or 1½ gallons has been expended in filling the interstices.

As about 6 gallons of tar will coat a cubic yard of 1½-inch to 2-inch

ranite, and as this will spread to the extent of 8 yards 3 inches thick, it follows that three-quarters of a gallon is employed to the superficial yard; cannot therefore be said to be grouted where a quarter of a gallon in xcess of the amount required to coat the surfaces of the stone is poured nto the interstices of a superficial yard of granite, and as the mixture icludes also sand and cement, with a grout of 1 gallon to the yard, is, to se a popular expression, asking for trouble. If grouting is to be a success must be properly done and the crevices properly filled up whatever uantity is required. Further, it is not desirable that the pitch should e too brittle or filled to a large extent with fine sand or cement. Softening in hot weather is undesirable. The pitch-grout method employed y Mr J. A. Brodie, M.Inst.C.E., and mentioned below under the ead of "Pitchmac," has been a success at Liverpool, but complaints ave been made where supposedly the same material has been used in he south of England in the summer months of the running of the pitch. Whether the same specification has or has not been used the writer cannot ay, but one factor must be taken into consideration, and that is that he atmospheric temperatures in London and the south of England are ifferent by many degrees from what is customary in Liverpool, and it quite possible that the consistency of the pitch must on that account e amended.

Mr Brodie's specification is as follows :—

Pitchmac.

1. The pitch must yield no matter volatile below 270° C. when subjected to dry distillation, and its total volatile organic matter must not fall below 30 per cent.
2. It must not contain more than 80 per cent. of its weight of matter insoluble in petroleum spirit of 0·700 specific gravity (boiling), and must be free from extraneous matter such as sand and grit.
3. It must twist fairly after immersion for two minutes in water at 60° F., but not under 55° F.

Creosote Oil.

1. The creosote oil shall be obtained exclusively by the distillation of coal tar, and not more than 6 per cent. shall redistil below 240° C.
2. The oil as obtained by the distillation of coal tar shall not be treated in any way either by the addition of any coal-tar product or by any extraction of its constituents, excepting such extraction as may be necessary to comply with the following requirements :—

3. It shall contain no solid matter at 15° C., and shall have a specific gravity of not less than 1·060 (taking water as 1·000 at 15° C.).
4. It must contain not less than 25 per cent. of its constituents that do not distil below 320° C., and the 75 per cent. which does distil over below 320° C. shall contain 10 per cent. of tar acids to be extracted by soda, specific gravity 1·125 (water 1·000).

The hot pitch and oil shall be tempered in a pitch boiler until it complies with the following practical tests :—

The mixture when cooled in water at 60° F. should stretch at least 3 feet before breaking, and the threads so formed should pull out very finely indeed. It should also, when doubled into a length of about a foot, bear hitting hard on an iron or stone surface without showing signs of cracking.

The author is inclined to think that this specification could be appreciably amended without altering the intentions of the designer; in some of the tests it is difficult to gauge their value.

The pitch-grout system is probably double the cost of tar macadam, but it has greater density, durability, and imperviousness, and traffic can pass over it immediately it is cold without any likelihood of damage. In the case of tar macadam it has frequently been noticeable that a heavy type of vehicle passing over the structure had disturbed the surface from end to end.

The macadam should be properly dry before the pitch grout is added, and this is a risk which necessitates the work being done in the summer only.

There is, however, some evidence indicating that this form of pavement, however crude it may appear to be in design, is one that is capable of satisfying the traffic requirements in an economical manner for a number of years.

Sidcup Trials.—A series of trials of various road structures were laid at Sidcup under the direction of the Road Board, and from a financial point of view they have shown good results.

Whether they are indeed the most economical depends on various factors, *e.g.* the estimated life of the pavement is not stated, the present surface condition is not indicated, the condition of the pavement in summer and winter conditions requires to be known; the actual cost when laid by the local authority should be equally desirable.

The experience of seven years is given in a table prepared by Mr T. Chapman, M.Inst.C.E., the county surveyor for Kent, who has very kindly permitted the reproduction of his chart in the Appendix.

Cost of Macadam and Pitch Grout.—It will be noted that the Section

No. 2 has cost 8½d. per superficial yard per annum. It must also be noted that the cost of the water-bound macadam was, according to the Road Board's Report on these trials published in 1913, at the rate of 2s. 5·65d. per annum, so that the saving by adopting this system amounts to 1s. 9·15d. per superficial yard per annum.

Taking the Section 23, which is that of a two-coat bituminous surface, the cost is stated as 1s. 1½d. per superficial yard per annum; but the original cost was 7s. 6d. per superficial yard, and as the road has been down seven years, the cost per annum equals 1s. 1d. approximately, therefore the cost of maintenance equals ½d. per superficial yard per annum.

But, as is stated elsewhere, exactly the same pavement has been laid by the writer at 4s. 6d. per superficial yard, and Mr Dryland, the county surveyor of Surrey, has laid several miles on the Brighton Road near Reigate at 4s. 7½d. per superficial yard; therefore, when the work is carried out by the local authority it can be done at a saving of 3s per superficial yard on the cost as laid at Sidcup, thus bringing the cost down to 7·9d. per superficial yard per annum over seven years, to which ½d. per superficial yard for maintenance equals 8·4d. as the total cost. The grouted macadam was laid by the Kent County Council, so that the two pavements are on the same basis, and the cost is approximately the same. The other pavements should obviously be compared on the same lines in order to obtain a true comparison.

The two-coat bituminous pavement has been laid in the writer's district for over twenty years, and the amount for repairs is exceedingly small; so that if this was a fair basis of the cost of maintenance and life, the cost per annum would with each year gradually reduce, so that the total cost spread over twenty years would amount to about 3½d. per superficial yard per annum, which would then bear a near approach to the cost of other pavements and bear a similar proportion to the amount of traffic that passes over the road with that which passes over the wood-paved roads.

Pitchmac is the name given to a standard mixture of pitch prepared by Mr Brodie, the city engineer of Liverpool, and used in the "pouring-in" process.

Plascom is the proprietary name given to a similarly used mixture of pitch, oil, and an impalpable mineral, filling as far as possible the whole of the crevices. One ton is used to cover 40 to 45 superficial yards of granite laid 2½ inches thick. This material does not seem to be affected by the hot weather, but is very hard and gives an appearance of being slippery to horse traffic.

The writer's experience of pitch grouting laid in the early summer

was apparently successful until the hot weather arrived, when the flowing of the pitch became such a nuisance that it had to be removed.

Val de Travers Matrix.—The bituminous matrix of the Val de Travers Asphalt Company is a mixture of bitumen and grit or other mineral matter, in which tar takes no part, although it may be added to cheapen the matrix. It is used as described in the pouring-in process.

The penetration method, as a whole, does not commend itself, for the reason that the stone into which the material is poured has not been heated and dried thoroughly free from moisture; the writer has seen the pouring in done while the stone was wet with recent rain.

Roadoleum is a residual oil in a solid form which is heated, and it is suggested should be used in the manner above described.

Trinidad Liquid Asphalt is another oil which it is said can be used in a somewhat similar manner or as a surface dressing. The material submitted to the writer was not of a character which would encourage its use, but it is subject to alteration, and therefore comments are not of great value.

Doubtless other mixtures of tar, pitch, residual oil, and bitumens will be brought forward in the future with more or less success. Anyone trying them would advisedly only do so in an experimental manner, as it is unwise to judge from the success that may have resulted from a few months' trial on any road. What may be a success in the summer may fail in the winter; what may successfully resist the traffic on one particular road may not equally successfully resist the traffic on another road. The climatic conditions in this country are very severe, and the traffic is more intense than it is in other countries, so that what may be successful abroad may have little success here. It is quite possible that many of the processes described will have success in certain thoroughfares, and the road engineer has to decide the choice of the road that the material suits. For economical reasons it is advisable that there should be a choice of compositions for road-construction purposes.

OTHER ROAD MATERIALS.

Lithomac.—The Limmer and Trinidad Lake Asphalt Company lay an asphalt macadam, composed of broken granite passing 1-inch mesh (thus including ¾-inch, ½-inch, and ⅜-inch sizes), sharp silica sand, and pure limestone powder, thoroughly mixed and carefully blended with refined elastic bitumen. It is a hot process, *i.e.* it is laid while the material is still hot. The success of this paving depends on the quality of the bitumen that is used, and also on the quantity compared with the mass of other material. A comment which is applicable to all pro-

cesses of a proprietary character is the work of the company in other but similar directions, e g. the Limmer and Trinidad Lake Asphalt Company has had a long experience in rock asphalt and mastic asphalt work, and therefore should be in a position to correct any imperfection if it should arise.

Asteophalte.—There are several methods employed; one is that a concrete foundation be provided, and on this is laid a binder course 1½ inches thick when compressed and subsequently an asphalt-wearing surface 1½ inches thick when compressed.

For medium traffic the penetration of the bitumen is 50 to 65 and for heavy traffic 40 to 55.

The binder course is graded stone from 1 inch down, mixed with the asphalt cement, the mixed material reaching the job at 200° to 325° F. and thoroughly compacted while in a hot condition.

The wearing surface has an average analysis as follows :—

Bitumen		12	per cent.
Passing	200 mesh	12	,,
,,	100 ,,	13	,,
,,	80 ,,	13	,,
,,	50 ,,	26	,,
,,	40 ,,	10	,,
,,	30 ,,	8	,,
,,	20 ,,	5	,,
,,	10 ,,	1	,,
		100	

The concrete is dispensed with in certain classes of roads and the binder course increased in thickness from 1½ inches to 3 or 4 inches.

A third method is to lay asphaltic concrete on the existing road surface; the thickness of the concrete may vary from 2 inches where the volume of traffic is large to 1 inch where the traffic is very light.

The materials of which the pavement is composed shall be crushed stone combined with a definite proportion of fine mineral aggregate and thoroughly mixed with asphalt cement.

The proportion of various grades to be as follows :—

40 per cent. by weight of crushed stone (max. size ⅓ thickness).
51 ,, ,, ,, fine mineral aggregate.
9 ,, ,, ,, of asphalt cement.

The fine mineral aggregate is the same as used in the binder course and the asphalt cement similar to that used for medium traffic.

The mixture is laid evenly with hot rakes, rolled, and the surface flushed with hot liquid astecphalte and afterwards coarse sand sprinkled over the surface and the surface thoroughly rolled before opening to traffic.

Mexphalte Paving is a road structure which is similar to that of astecphalte described above. The base-coat or binder course is composed of coarse to fine material graded and mixed with mexphalte bitumen. The thickness of this coat is about 3 inches. The wearing surface has an analysis similar to that of the astecphalte-wearing surface and conforms closely to that of other asphalt-wearing surfaces described elsewhere, but the bitumen employed is mexphalte.

This paving has been laid down in a number of roads in this country and abroad.

Cormastik is a mixture composed of mineral matter and Sicilian rock asphalt, fluxed with Cuban bitumen, which is laid in a manner similar to that of mastic asphalt, but is placed on the existing road surface. One or two trial lengths have been laid, and with other new processes will have to withstand the tests of traffic and weather. As one might expect from the previous chapter, there are indications of hardness, slipperiness, and non-recuperative power.

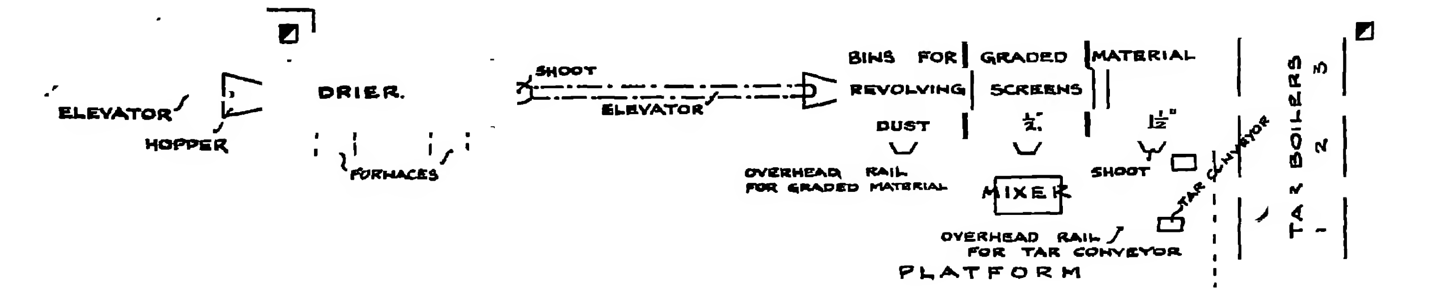
Rocmac is a composition of silicate of soda, sugar, and other ingredients, and a specially selected limestone which contains a large proportion of carbonate of lime This mixture is laid on the bottom of the road which has been prepared for a coat of macadam, and the granite is rolled into the Rocmac mixture until it fills the interstices between the stones and thus acts as the binding material. This may prove to be better than the ordinary water-bound macadam, but it is questionable whether it has that resiliency that is necessary in an ideal road, and from the section the writer saw in hot weather with traffic there was a proportion of dust, although not so great as in the case of the macadam road.

Roadamant is another specialised material; it is a mastic asphalt, and laid on a concrete foundation, or on the existing road surface.

Trials have been made with a variety of materials, but none of them have justified extension, either on account of prohibitive price or by reason of inherent defects.

The *bituminous-macadam* structure and other processes in which tar and bitumen have taken a part, and which appear to meet in large measure the criticisms that have been raised, appear to the writer of sufficient importance to be described in a separate chapter.

The plant for the manufacture of tar macadam is built in various ways, but the simplest one that appears to the author is composed of



Plan.

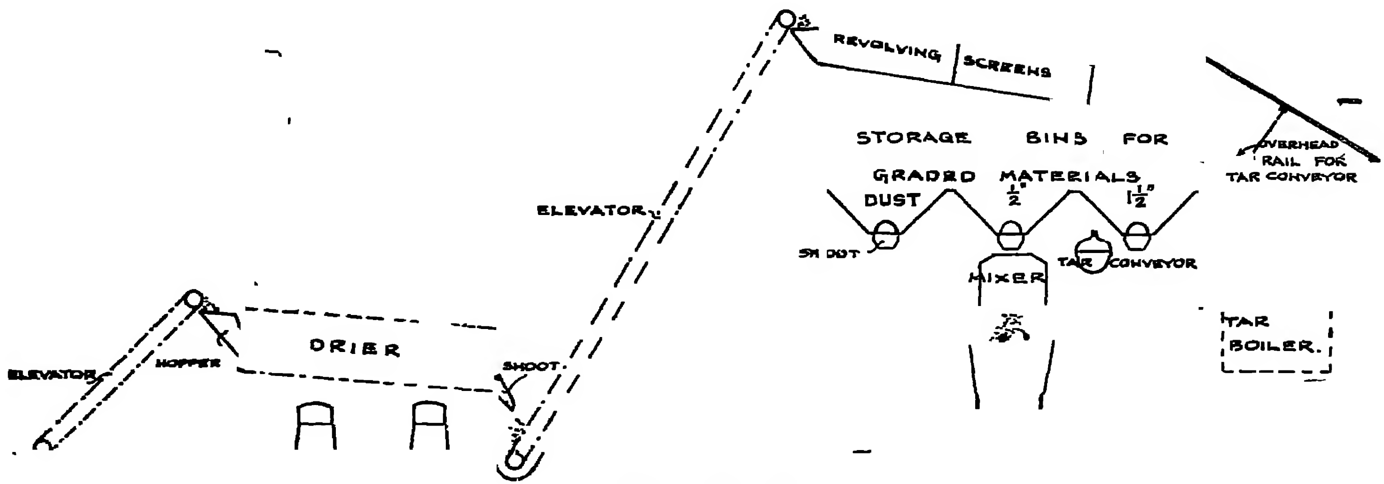


FIG. 31.—Elevation.

a drier of the rotary type, which heats the stone to a temperature withi the limits necessary for either tar-macadam or bituminous mixtures The number of these driers depends on the number of units desired each unit will heat about 20 tons per day. One mixer can mix at th

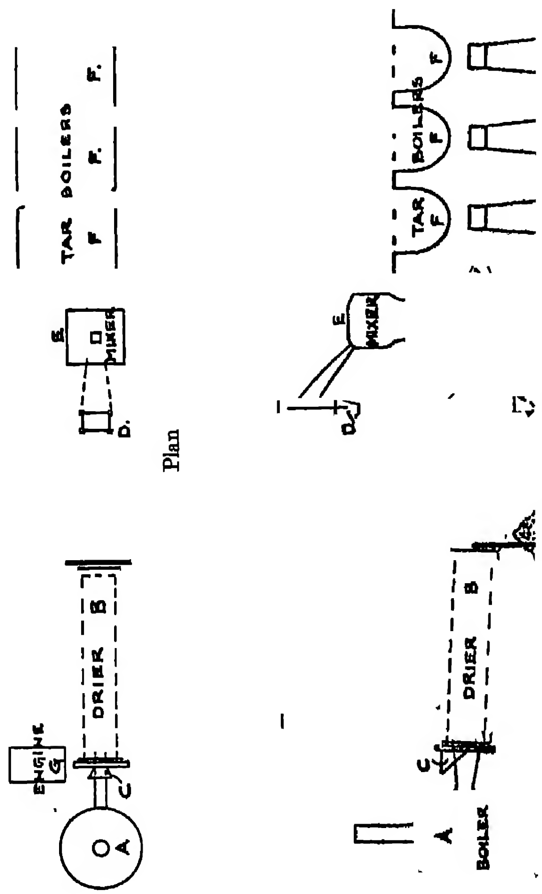


FIG. 32.—Elevation.

rate of about 50 tons per day. Tanks for the tar or bitumen are usuall built so as to allow about 5 tons to be heated at one time.

Where dehydrated tar only is being used, then it may be desirable t have large tanks where it can be stored, the tar being received by tan loads and pumped by mechanical pumps. This tank would be place at such a height that the tar can gravitate to the part of the depôt i which it is required. But some engineers find it more satisfactory t

prepare their own tar by cutting back pitch with creosote or anthracene oils; the pitch and the necessary oils or tars are more easily stored.

The sketches below indicate a complete plant necessary for a continuous output of about 20 tons per day.

Another type of plant (Figs. 32 and 32A) erected at Fulham. A is the boiler, which raises the steam necessary to drive engine G; the latter is employed in revolving the drier. The flame from the boiler, instead of being passed up the chimney at A, passes through the drier and round it back again to chimney H. B is the drier; in the interior is a revolving drum. The material to be dried is thrown by manual labour into the hopper C and discharges at K. The time taken to heat the stone is three minutes, and its temperature is about 400° F. when it emerges at K. It is then shovelled into the hopper D, which is raised by power to the top of the mixer, where it is automatically tipped into the mixer, immediately it resumes its vertical position and returns to the bottom for a second load. As soon as the material is placed in the mixer, the man there is ready with the required quantity of tar composition, and while the hopper D is returning to deposit its next batch of material, the mixer has thoroughly mixed the batch; the man opens the bottom of the mixer and allows the mixture to drop to the waiting cart.

FIG. 32A.—View of plant for drying, heating, and mixing with either tar or bitumen material for road composition

CHAPTER IX.

METHODS OF USING TAR AND BITUMEN (*continued*).

Essentials in a Road Structure.—From preceding chapters it will be gathered that there are a series of factors which are essential and others which must be regarded as economical, both of which are important in a successful form of road construction. They are:—That the structure shall be impervious to moisture, and able to throw the water quickly off the surface: that it shall be resilient both in winter and summer; and the binding agent, therefore, ductile and adhesive (ductility being placed first on account of its greater importance): that the thickness shall not exceed 4 inches—this latter depends on the homogeneity: that the structure is like concrete, self-contained: and that the foundation or substructure shall be satisfactory.

Tendency of Traffic.—The remarkable effect of waterproofing the surface that has already been mentioned, and shown in the diagram on page 244, is mainly due to tar-spraying. This form of treatment has to be considered as annual on account of the tar losing its power in the autumn, but there are features which ought not to be lost sight of: at the sides of the road the tar retains to a greater degree its power of waterproofing even during the winter, showing that it is the traffic that causes the disintegration, and that if the tar is left undisturbed it will last much longer than one winter.

This peculiarity suggests that this part of the road is not used, and therefore the thickness of the structure might be lessened or, if it was practicable, a weaker material might be substituted. But the better course would be to flatten the camber so that the traffic is encouraged to traverse the sides of the road equally with the centre.

That there is a tendency for the traffic to keep in the centre of the road is to be gathered from the fact that the wear at the sides of a wood-paved or asphalt road is much less than elsewhere.

Thickness of Material.—If 2 to 2½ inches (Chapter IV.) will distribute the pressure satisfactorily on to the prepared foundation, then from 2 to 2½ inches is all that is required at the sides—but in the middle third of the width of the road the thickness should be increased to 4 inches at least, in order to allow ½ inch to 1 inch of wear. When this amount of wear is noticed, then the road should be repaired and again brought to its original condition. The advantage of any road surface that can be repaired by placing an inch layer of material is obvious.

Effect of Wear on Composition of Road.—In a previous chapter it has been shown that an ordinary *water-bound macadam* road consists of:—

Macadam stone	55 to 60 per cent.
Hoggin or chippings and fine material	25 ,, 35 ,,
Moisture	5 ,, 10 ,,

If the analysis is divided so as to show the proportions of material above and below ½ inch, the following percentages will apply :—

Above ½ inch	65 per cent.
Below ½ ,, ...	35 ,,

But if the proportions are taken when the road has been subjected to traffic and in a firm condition, it will be found that the proportion is :—

Above ½ inch . . .	55 to 60 per cent.	(coarse)
Below ½ ,, . . .	45 ,, 40 ,,	(fine)

If, therefore, the best form of macadam road is taken as a guide, and an adhesive and ductile binding agent is used in place of water or moisture, the above proportions should be followed to obtain all the other constituent parts.

Comparison with Cement Concrete.—If another example is sought for, the cement concrete foundation of a wood-paved road would probably serve, the floated cement coat not being taken into consideration. The usual proportions are 6 of Thames ballast to 1 of Portland cement and moisture. Screening out the stone above ½ inch and below:—

3½ to 4 of stone above ½ inch	=50 to 57 per cent.
2½ ,, 2 ,, sand below ½ ,,	=36 ,, 29 ,,
1 ,, cement	=14·0 ,,

If the amount of moisture is taken into consideration, then the proportions agree even more closely with the above figures for a macadam road.

Cement concrete roads have not been considered to be a success on account of the non-resiliency and the brittleness of the surface composition; this is undoubtedly the case, but whether it is a serious factor is open to discussion, and will be dealt with in a separate chapter. One of the principal disadvantages was also that the concrete would crack and become unsightly. The writer laid an area in 1908 in order to find whether a thickness of 3 inches would withstand traffic which was subjected to being tipped upon, and on which cabs and carriages were in the habit of standing, etc. The composition was of granite chippings and dust, clinker $\frac{3}{8}$ inch in size, sand and cement in the proportion of 4 to 1, the proportion of fine material to coarse being about 55 per cent. to 45 per cent. The surface was ribbed about $\frac{1}{2}$ inch deep and about 4 inches apart. The ribs practically disappeared in two years, the surface was never slippery, there was not even the sign of a crack, and as it cost only 1s. 4d. per superficial yard, it has been highly successful. It is probably due to the mixture of clinker ash with the granite chippings that the concrete face shows no signs of cracking, as the porosity of this ash would allow the moisture that it may receive to expand in its own interior.

As, however, it is necessary to have a resilient surface, no further extension of this surfacing has been laid.

BITUMINOUS MACADAM.

Series of Experiments.—The first series of experiments carried out by the writer were made with the object of finding the necessary ductile binding agent for the fine material. The trials with tar were not in any case successful, the tar not being sufficiently ductile, and to obtain ductility a large amount was required, which would prove objectionable in warm weather; when the quantity was reduced and hardened or softened, the composition was too hard or too friable, not giving as great an advantage as could be gained by using Portland cement. This was an indication that tar, although it may be very adhesive and ductile in bulk, was not very adhesive or ductile when in a thin layer. Therefore, various bitumens were used, but Trinidad Lake bitumen gave the best results.

Further knowledge of this material would seem to indicate that the success of this bitumen was due to the "colloids" or fine impalpable powder or filler naturally placed in the bitumen, because subsequent experiments with tar adequately filled with fine material gave results which, if this colloid theory had been realised at the time, would have encouraged this material or others to be more extensively tested.

Tests with Various Mixtures.—Having obtained this, it was thought that instead of large stone being used in the making up of the bituminous concrete, small-sized stone would give better results, and a number of mixtures were made, with the result that a small area was laid at a place where the traffic was sufficiently severe to test it, in the following proportions :—

Limestone chippings, ¾ inch . .	54	per cent.
Fine sand	20	,,
Limestone dust	13·5	,,
Bitumen	12·5	,,

This section was laid in 1906, but after a few months, it having stood the traffic remarkably well, it was removed on account of certain improvements that had to be made. A trial length was therefore laid in the spring of 1908 with an admixture of mastic asphalt, the fine material in the mastic having been calculated, the proportions were :—

Granite chippings . . .	52	per cent.
Sand	26	,,
Fine material .	12	,,
Bitumen	10	,,

This failed after having been down about nine months, but in another road it still remains ; although it must be said that the traffic on this section, which was at the time somewhat severe, was for some reason or other taken off later on. The laying of this material also proved rather onerous, before it could be got into a properly consolidated state. Another sample was laid, using limestone chippings instead of granite chippings, in the place of the one that lasted only nine months ; this consisted of :—

Limestone chippings . . .	58·7	per cent.
Sand	29·5	,,
Bitumen	11·8	,,

This material also required delicate handling when placed on the road, as only a comparatively light hand-roller could be used to compress the mass together. But the results have been very satisfactory, and the section still remains, having been laid in May 1909.

In the summer of 1908 sufficient information had been gained to justify the laying of a lightly trafficked street. The road was scarified and rolled until the foundation was sufficiently substantial, and the depth of 1½ inches was left for the following composition :—

$\frac{3}{4}$-inch clinker	63 per cent.
Granite chippings	1·5 ,,
Sand	23 ,,
Fine dust	4 ,,
Bitumen	8·5 ,,

This road has required no attention since it was laid. The rolling of the material was carried out by means of a 10-ton steam-roller, with wheels 5 feet wide back and front, so that the weight per foot was not very much greater than a heavy hand-roller

In May 1909 another road was laid, but in this case 2-inch granite was used together with chippings, and only the dust of the latter to make up the fine material :—

2-inch granite and chippings	70 per cent. (about).
Sand	16 ,,
Cement	6 ,,
Bitumen	8 ,,

This road has shown signs of disintegration, especially in the winter. Curiously, however, it closes up in the summer, but it is evident that it would not prove satisfactory for heavy traffic. No repairs have had to be made to the surface, and probably for the road in which it is laid it will prove satisfactory; the disintegration is where the traffic concentrates in the centre of the road, and it would only require to be repaired by taking this portion out, and re-treating on a better basis, whenever the surface should demand it.

In 1910 another road was laid on somewhat the same lines, the finest material being cut down :—

2-inch granite and chippings	73·5 per cent.
Sand	18·7 ,,
Bitumen	7·8 ,,

This road has withstood the traffic remarkably well, but during the winter there was slight evidence of ravelling, which is probably due to either insufficiency in bitumen or that it was too hard; and as in the summer the material closed up with a satisfactory surface, this would indicate that the bitumen would be more satisfactory if it was of a softer consistency, and there was also an indication that the fine stuff was in too small a quantity.

Causes of Failure and Successful Proportions.—Various alterations were made in the consistency to suit the defects which developed, until the constituents came back to the form in the macadam road, as was

the case in the first experiments, except that the large stone was substituted for the small. The most recent and generally most satisfactory is indicated in the following proportions :—

Granite and chippings	61 per cent.
Sand and dust	30 ,,
Bitumen	9 ,,

Possibly an even better road will have the proportions about 55 per cent. and 45 per cent., but whether the stone be large or small, the division between the two must be between 50 and 60 per cent., and 50 and 40 per cent., as is evident in the case of the cement concrete ; the bitumen that is required in each case being a matter of calculation and trial in a road surface.

Another method which seems to have the elements of success, especially for light-trafficked roads, is to lay

Granite chippings, ½ inch . . .	58 per cent.
Fine sand	30 ,,
Bitumen	12 ,,

This material would be laid at least 2 inches thick on a good foundation.

Tar Footpaths.—An examination of tar footpaths which have been down for at least fifteen years shows a very similar appearance in cross section to that which this form of bituminous concrete takes, the difference only being that the tar concrete is brittle and there is not quite the same proportion of very fine material in the mixture. A section of an asphalt mixture made with the same bitumen after about ten years was as lively as if it had only recently been laid. The density of the composition has doubtless much to do with the bitumen retaining its elasticity after such a long period, but the oils which are used to flux the bitumen are not so easily volatilised, as is the case with the oils used for the fluxing of the pitch. Also, there are no constituents in the bitumen which become solid at or below 50° F., as is the case with tar.

Bituminous Macadam.—There are a number of interesting items in connection with the process of mixing this class of bituminous concrete. The first is that every particle of moisture must be eliminated, and the stone is therefore heated to a high temperature, and whilst in its very hot condition is sent to the mixing pan. A definite quantity of stone and of bitumen is placed in the mixer, in order that each batch shall be precisely the same ; if the proportions vary there is at once evidence of a surplus of bitumen or a shortage of it. The composition must look rich, but not so rich as to find its level too rapidly when placed in the

rt. The appearance of the mixture to an experienced eye will enable correction to be made. Even ½ per cent. addition of bitumen will ake a very great difference in the consistency. The temperature of stone and the bitumen should be practically the same while being xed.

To try and make the mixture by hand is most arduous and slow, sides being unsatisfactory. The area laid by the writer with all the pliances that are available in an ordinary municipal depôt was only the rate of 9 cubic yards per day. The heating of the stone to the quired temperature (about 400° F.) was erratic, and by the time at there was sufficient heated to make a mixture the temperature d dropped to about 250° F. It was quite evident that rapid heating d the ability to store the stone in a hot state was necessary, and that mixture should be made equally rapidly was also essential. The ne occupied in turning it over the number of times to ensure the whole the stone and fine material being thoroughly coated was so long at the composition could scarcely be lifted even with hot shovels; men were also careless about the heating of the shovels, getting em almost red hot and thus carbonising the bitumen with which ey came in contact

Plant for Bituminous Concrete.—The pre-war cost of the machinery cessary to turn out about 60 to 70 tons per day was about £1500 [1] The chinery is by no means of a complicated character, but it must be very bstantial, as may be gathered from the character of the stone to be used, rapidity with which the mixture is made, and the quantity turned out r day. The same plant would be equally useful for mixing tar macadam.

Probably the most accurate but more complicated method would to coat the aggregate, *i.e.* the large stone first and then mix it with simultaneously prepared bituminous matrix; but, provided the heat the stone is maintained, there seems to have been no difficulty in xing the whole of the material in one operation.

Thickness laid.—About 4 miles of roads have been laid, and the aterial has been subjected to every variety of traffic. In no case s the thickness exceeded 3 inches, *i.e* about 7 to 8 yards to the ton, d in some side streets it has been laid only 2 inches thick, *i.e.* about yards to the ton. If lighter material than granite is used, the yardage proportionately increased to obtain the same thickness.

The laying is carried out in precisely the same manner as for the dinary macadam road, and with a similar steam-roller to that used macadam construction. It is, of course, laid while hot, and the lling is brought right up to the area where the material is being laid;

[1] Present costs are about £4500.

.e. the rolling must be done while it is in a hot condition, in order to .ompress it to a proper thickness and obtain a dense section. The weight of the roller should be 6 to 8 tons, not heavier, and the type of 'oller that will be most satisfactory both for this class of pavement and the tar-macadam pavements will be the rollers fitted with tandem wheels. Care has to be taken in laying, that if segregation has occurred n the cartage over a long distance, so to place the aggregate with the ine material, that it is not too much in any one place. About 500 to 300 superficial yards can be laid in one day, complete and ready for the traffic the following day.

Finishing Surface.—When the rolling is completed and an even surface is obtained, there is an appearance of holes which would hold water in. In order to give the structure time to work up and make a perfectly even surface with no crevices, a squeegee coat of bitumen s placed over the surface to ensure it being perfectly watertight, on which ¼-inch clean chippings are lightly sprinkled. These are quickly absorbed by the bitumen, but, just as the road is completed, it does not look as well as some might expect; it, however, rapidly smooths out under traffic.

Stones held in position by Matrix.—An examination of a section of the road structure so made shows that the stones are held in position by the matrix of finer material, and that this holding up of the stones may be regarded as permanent, one may therefore conclude that there will be no attrition of the stone in this form of construction, and that only actual traffic wear should affect the material. This being the case, the aggregate may be altered to suit local circumstances; *i.e.* if a local hard stone is available, it might serve equally as well as granite, and be very much cheaper. The same argument applies in cement concrete, as broken bricks and other locally obtainable hard stones are used instead of the hardest material, such as granite, which might be assumed to be the best for cement concrete.

Wearing Capacity—Local Stone as Aggregate.—The strength of a composition depends on its weakest component, and the same applies in road construction; the wear of a road made up of a granite and a matrix of fine material and bitumen, depends on the wearing capacity of the weaker of the two parts, which in this case is the matrix. It may therefore be assumed that a road composed of material that has an aggregate and a matrix will give more satisfactory results if the aggregate is of the same wearing capacity as the matrix; therefore, it may be found that limestone, Kentish ragstone, sandstone, and flag rock, which are all composed of somewhat similar particles, will answer more satisfactorily than granite.

With the object of testing whether an aggregate of this nature would prove satisfactory, the Road Board entertained a proposal, and sections have been laid in a road having the same traffic passing over each section, the classes of aggregate being—

(a) Granite.
(b) Slag.
(c) Kentish ragstone equal with limestone.
(d) Flag rock (Yorkshire).
(e) Picked clinker refuse (destructor).

In order to also test how much pitch and oil would detrimentally affect the bitumen, there were, in addition, sections laid with the bituminous matter containing in one case 20 per cent. of pitch and

FIG. 33.—The white areas show the aggregate and the black areas the matrix.

oil, in another with 30 per cent., and a third with 40 per cent., these sections being duplicated in limestone and granite. As these areas were only laid in September 1911, no precise information can be given at present as to what the results are likely to be.

Tarred Old Stone Base and Bituminous Surface.—A further section has been laid using the old macadam taken from the road, passing it through the heater, and subsequently tarring it with a consistency of pitch and oil (84 per cent. and 16 per cent.), in accord as far as possible with the Road Board's specification.[1] This was laid hot, and immediately rolled to an even surface, on the top of which was laid a coat 1 inch thick of the bituminous matrix for the surface wear. By this method the maximum use of locally obtained material is secured and a minimum of a proprietary material.

The bitumen used throughout these experiments was the Trinidad Lake bitumen An actual sectional view is shown in fig 33.

[1] This is now substituted by the Engineering Standards Committee's specification, which appears in the Appendix.

The weight of the various aggregates are as follows :—

	Weight per Cubic Feet.	
Granite	90 lbs.	Sand 90 to 107.
Slag	96 ,,	Lime 30.
Flag rock . . .	82 ,,	Chippings (granite) 85.
Ragstone	82 ,	Dust ,,
Clinker . . .	68 ,,	Limestone (⅛ to dust) 82.

The specific gravity of the pitch was 1·33, and of the oil 1·06, the mixture being of specific gravity 1·27. The specific gravity of the bitumen was also 1·27. The amount of pitch and oil used in the tarring of the old macadam was about 7 per cent., the mixture being heated until all moisture was thoroughly eliminated and the surface in the pan was smooth and glossy at 270° F.

Cost.—The cost of the bituminous macadam was in Fulham from 3s. 1d. to 4s. 3d. per superficial yard, allowing in some cases for the old material that was taken out of the road at about 6s. per ton (which had been used in the bituminous concrete).

The road structure that appears to the writer to give the most satisfactory results, having regard to its first cost (in normal times), its life and capacity for resisting, practically speaking, any form of traffic, its cleanliness, and low maintenance, is the two-coat bituminous paving. The fact that so many kinds of materials have been used to form the aggregate gives it a much greater recommendation for favourable consideration also because the only imported material is the bitumen, which amounts to a small percentage of the whole.

The base-coat is laid 3 inches thick and is, so far as the aggregate is concerned, made precisely as cement concrete is made, and, practically speaking, in the same proportions. The material should be broken with sharp arrises, but it may be composed of clinker, broken sandstone, limestone, granite, etc. etc. The old granite taken from an existing road, including the ¾-inch, ½-inch, ¼-inch, and a small percentage of dust, will equally serve. This should be heated and mixed with hot tar to a consistency of about 120° at 60° F. in a penetrometer. It will spread at the rate of 7 to 8 yards to the ton and give the necessary thickness. This should cost not more than about 1s. 9d. per superficial yard laid. The surface after rolling—which is to be done while the material is still hot—will or should give by the number of crevices a good key for the surfacing mixture ; if it is too smooth, it is evident that there has been too much fine material in the mixture, and the excess should be removed.

The bituminous surface coat may have an aggregate of sand, granite,

dust, and cement, or any other free mineral substance which will give an equal grading to those shown elsewhere for wearing-surface mixtures. If limestone, sandstone, and granite are to be employed, or any other stone which requires breaking, probably the best form of crusher for the purpose is what is known as the "Lightning Crusher," which from the examples submitted to the writer gives a very good graded material; but the grading must be carefully adjusted, and it is better to obtain sand if it is available of the necessary size. The cement is not used because of its cementing qualities, but because of its fine grading; any other free powder similarly graded will serve the purpose equally well. The amount of bitumen can be easily calculated.

The author has used Trinidad Lake bitumen, but it is not necessary that it should be strictly confined to this bitumen if others will give equally satisfactory results, as there is promise in that direction. Using the bitumen as indicated, the cost pre-war is as follows:—

17 per cent Trinidad Lake fluxed bitumen, £6, 10s.[1]	£1	3	0
15 ,, cement, £1, 10s.[2]	0	1	6
68 ,, sand and granite, 6s. .	0	4	1
Heating and power	0	3	5
Labour	0	3	0
Other charges	0	2	0
	£2	0	0[3]

This would spread at the rate of 20 yards to the ton and bring the cost to 2s. per superficial yard. The cost of laying, cartage, rolling, etc., would be about 9d. per superficial yard, making a total of 4s. 6d. per superficial yard

Where heavy traffic is in evidence the thickness would advisedly be increased to about 1½ inches.

Whenever any worn area requires to be repaired, this can with comparative ease be rapidly carried out, even if it is only required to be ¾ inch or 1 inch thick

Efficacy considered.—The road constructed of bituminous macadam has been subjected to moderately severe tests, and has come out of them so far in a remarkably satisfactory manner, especially so when the cost in considered It would seem that for roads with such traffic as is indicated by the three tables on pages 183–5, it would prove to be a very useful pavement, but there must be a limit because of the nature of the material making up the composition; 60 per cent. is stone, the particles

[1] Present cost = £17 per ton. [2] Present cost = £4 per ton.
[3] Present cost = £4, 10s. per ton.

of which are bound together by an agent totally different from that of the remaining 40 per cent., which is composed of particles bound together with bitumen. The two materials must at some time or other come into opposition, and it may be assumed that this will be the case when the traffic is severe and continuous. When the weather is agreeable to both, probably the material would withstand any traffic, however severe; if the weather should be too hot, the possibilities are that the surface might become somewhat soft, and on this account be affected adversely; it has been pointed out that the writer has had some defective areas which have been evident in cold weather, due to an insufficient quantity of bitumen, or probably to a too rigid adherence to a specific formula, applying it to both light- and heavy-trafficked roads. Light-trafficked roads may be dealt with successfully even where there may be a comparative weakness in bitumen, but where the traffic is heavy and concentrated the formula must be amended and the amount of bitumen increased. This assumption is essential from an analytical examination of the structure. The increased quantity in the structure allows the large stones to have a better cushion, and supplies the resiliency of which the cold weather has deprived the structure by increasing the hardness and rendering the air-spaces less effective.

One method for securing this is to reduce the size of the stone from 2 inches to 1 inch · the bitumen would have to be increased, but the advantage of using the larger stone is that the old stone in the road may be used, and it would involve greater cost if it had to be broken to a smaller size.

It is the amount of bitumen in the bituminous surface mixture which makes this pavement the success it is under heavy traffic. Each particle is embedded in the bitumen, which even in cold temperatures has sufficient viscosity and ductility to take up and transfer the pressure to the adjoining particles, and in this way no particle is materially altered in its position. This surface mixture on a tarred old macadam base will probably be more satisfactory from every point of view, but in the meantime the process requires to be treated carefully as to the satisfactory character of the tarred foundation, the outcome of which, in the writer's opinion, is certain. This mixture has already been proved a success for many years on bituminous concrete base, and the tarred base ought to be equally satisfactory, sealed as it is away from the atmosphere.

Scientific Examination.—It will be seen that in road construction there is room not only for considerable scientific examination as to the suitability of the various materials making up the composition of a road structure, but also into the composition as a whole, together with an examination into the exact limits of any particular form of construction

for any definite class or rate of traffic. The results can only be definitely determined after several years' actual traffic and weather conditions

With motor traction and resilient tires such tabled information will have greater value than could be possible with horse traffic and non-resilient tires in the majority.

Further, considerable knowledge, skill, and sympathy will be required in order to obtain the successful results that are sought for. Road structures must not in the future be left to the care of the "old hand," scientific methods must prevail not only with the staff, but with the employees engaged in mixing and laying the material, and still more so with those engaged in repairs.

In laying the material down on the road, the weather conditions must be studied and prepared for; the surface of the base-coat must be clean and dry. In laying the topping or wearing-surface mixture, care must be exercised that the tools employed are not too hot, so as to burn the bitumen to coke; the material must be well raked and punned in with the back edge of the rake so as to ensure an even thickness. If it is not done evenly, the unevenness will be exposed as soon as the roller passes over it, there will be patches of a honeycomb appearance The jointing up with the area laid the previous day must be overlaid with hot material in order to soften the previously laid material; then, when it is sufficiently softened, it will make an adhesive and complete joint. Special tamping at the joint will also be necessary before the roller is allowed on to the new work. Where manhole covers are placed in the road there should be a slightly increased thickness immediately surrounding the cover, and this also specially tamped; at the junction with the channels it must be similarly treated.

The rolling should be longitudinally and cross-rolled and in half-circles so as to ensure a good surface.

Repairs.—When repairs are to be made it is usual to employ fire baskets or gas burners. The fire basket is about 5 feet × 2 feet × 9 inches, and is made of iron wire interlaced so as to give about 1½-inch mesh. A coke fire is placed in this cagework and the bottom of the framework is kept about 6 inches from the surface of the road to be treated, by means of supports. At one end is a trolley wheel and at the other end are handles, so that the basket can be quickly moved from one area to another.

The heat softens the wearing surface and it can be easily shovelled away, leaving the base exposed. If it is only a patch that is required to be made, the area outside the portion shovelled away is cut vertically by means of a chisel and hammer, leaving a regular thickness of at least ¾ inch.

If the material has not been burnt but merely softened, it can be re-

melted in a suitable pan and used with new material to make up the amount required to make a sound job. The same care and trouble must be taken in laying this area as in laying the new material. Frequently, however, the men employed do not exercise that care and judgment which is necessary to ensure a satisfactory job

The pan that is used for reheating the wearing-surface material is similar to an ordinary sand-drier. It is about 7 feet long and 4 feet wide; the bottom is a curved plate, and on the top are covers which can be opened and closed in two lengths. Under the bottom plate is a second plate placed about 2 inches below the first one, and this second plate is in direct contact with the fire underneath. If ordinary care is exercised it will be evident that the material cannot be burnt in such a machine; but from the results in some instances the stoking must have been very severe or the material left in for an excessively long time, because in a few weeks the material has disintegrated and it is quite evident that the bitumen has been coked.

The repaired area, in fact, if it is carefully attended to, should be fully equal to the material which was laid originally.

The tests mentioned on page 177 have been in existence about seven years, and the previous notes were written in 1912. The results, although satisfactory from the point of view of the cost over what was the case when the roads were macadamised, are not so satisfactory as had been hoped for. On the other hand, valuable information has been derived from them :—

(*a*) The granite section was the most satisfactory, and lasted about six years.
(*b*) The slag section was not very satisfactory, and was very little better than the three following sections :—
(*c*) The Kentish ragstone after the second year pulverised, and the fractured stone became easily noticeable.
(*d*) Flag rock had the same characteristic.
(*e*) Picked clinker refuse was, if anything, better than the previous three, (*b*), (*c*), and (*d*).

Many repairs had to be made in all the sections except (*a*), until eventually it was decided to use the material again by taking it up, heating it, and laying it down again as a base for a wearing surface of bituminous material.

Conclusions from Tests.—It was very evident from a close examination that where the stone fractured, the fragments would for some time remain embedded; but they gradually wore, and although this material amalgamated with the surplus bitumen, long hollows were formed so that in places the original thickness was somewhat exceeded, and there

TABLE XXVIII.—ANALYSIS OF TRAFFIC.

Three Roads, treated with Bituminous Macadam.

MARCH 1911.—ONE WEEK'S TRAFFIC TAKEN AT ONGAR ROAD, FULHAM. ROAD WIDTH 10 3 YARDS.

	Wed. 6 to 6	Thur. 6 to 6	Fri. 6 to 6	Sat. 6 to 6	Sun. 9 to 9	Mon. 9 to 9	Tues. 6 to 6	Tues. Night. 9 p.m. to 9 a m.	No.	Tons.
Bicycles and tricycles	468	439	469	560	34	512	537	240×7=1680	4695	422·5
Motor :—Motor cars and cabs	525	514	606	595	261	552	512	309×7=2163	5728	9164·8
Motor omnibus	5	8	9	6	1	5	4	2×7=14	52	312
Motor vans, light	8	11	3	6	..	6	15	..	49	78·4
„ „ medium	11	9	8	13	..	19	7	2×7=14	81	202 5
„ „ heavy	..	3	2	2	..	5	1	..	13	65
Motor lorries, heavy	19	23	25	6	..	22	19	..	114	1140
Trailers	3	7	14	3	..	5	7	..	39	195
Motor cycles	2	8	7	11	..	2	5	2×7=14	49	6 3
Horse :—2-wheeled, light	26	27	24	28	4	33	35	12×7=84	261	261
2 „ heavy	19	18	27	22	..	11	21	1×7=7	125	312·5
4 „ light, and carriages	412	413	415	368	32	425	377	73×7×511	2953	7382·5
4 „ light (2-horse)	15	21	11	13	.	10	10	..	80	200
4 „ medium „	24	20	48	34	1	38	39	3×7=21	225	675
4 „ heavy „	17	27	18	29	.	24	19	1×7=7	141	987
Horses (led or ridden)	12	27	19	23	2	19	9	4×7=28	139	83 4
Hand carts and barrows	162	165	117	165	53	116	117	30×7=210	1105	110 5
									15849	22498 4

Total, tons per day . . 3214
„ tons per hour . . 133
„ tons per yard width . 13

N.B.—The traffic in this case concentrates on a width of 14 feet, and the tonnage per yard width should read 27.

TABLE XXVIII.—*continued.*

MARCH 1911.—ONE WEEK'S TRAFFIC TAKEN AT HALFORD ROAD, FULHAM. ROAD WIDTH 10 77 YARDS.

	Tues 6 to 6	Wed. 6 to 6	Thur 6 to 6	Fri. 6 to 6	Sat 9 to 9	Sun 9 to 9	Mon. 6 to 6	Tues Night. 9 p.m to 9 a.m	No.	Tons.
Bicycles and tricycles	297	265	286	242	296	105	247	149×7=1043	2781	250 2
Motor.—Motor cars and cabs	391	463	425	445	454	217	424	240×7=1680	4499	7198 4
Motor omnibus	26	22	6	13	7	1	9	1×7=7	91	546
Motor vans, light	2	5	4	1	2	.	4	2×7=14	32	51·2
„ „ medium	7	..	8	4	3	.	9	1×7=7	38	95
„ „ heavy	1		1	..	6	.	.	.	8	40
Motor lorries, heavy	5	5	7	6	4	.	5	.	32	320
Trailers	1	..	.	.	..	.	.	..	1	5
Motor cycles	1	..	3	1	1	1	3	2×7=14	24	3
Horse :—2-wheeled, light	13	21	7	15	17	3	11	13×7=91	178	178
2 „ heavy	1	.	..	8	2		3	..	14	35
4 „ light, and carriages	174	216	165	232	208	12	229	66×7=462	1698	4245
4 „ light (2-horse)	4	4	3	..	5		1		17	42 5
4 „ medium „	15	16	16	13	15		19	.	94	282
4 „ heavy „	18	3	11	7	13	.	19	..	71	497
Horses (led or ridden)	17	17	22	14	12	4	17	13×7=91	194	116 4
Hand carts and barrows	112	118	99	127	120	37	119	29×7=203	935	93·5
									10707	13998 3

Total, tons per day	1999 7
„ tons per hour	83 3
„ tons per yard width	7 7

TABLE XXVIII.—*continued*

MARCH 1911.—ONE WEEK'S TRAFFIC TAKEN AT BAGLEY'S LANE, FULHAM. ROAD WIDTH 9·77 YARDS

	Thur 6 to 6	Fri. 6 to 6	Sat. 6 to 6	Sun. 9 to 9	Mon. 9 to 9	Tues. 6 to 6	Wed. 6 to 6	Tues. Night. 9 p.m to 9 a.m	No	Tons.
Bicycles and tricycles	215	199	229	140	205	186	184	98×7=686	2044	183 9
Motor :—Motor cars and cabs	12	8	9	13	15	13	13	.	83	132 8
Motor omnibus	..	1	..	1	..	..	.	..	2	12
Motor vans, light	.	..	..	..	3		3	.	6	9 6
„ „ medium	4	8	4	..	5	4	3	4×7=28	56	140
„ „ heavy	..	..	..		5	2	2	.	9	45
Motor lorries, heavy	2	2	.	..	2	1	2	.	9	90
Trailers	..	..	.	..		1			1	5
Motor cycles	..	..	1	4	.		2	.	7	0 9
Horse :—2-wheeled, light	21	16	31	18	21	24	26	11×7=77	234	234
2 „ heavy	23	14	38	..	52	61	4	11×7=77	269	672 5
4 „ light, and carriages	285	306	259	39	307	304	221	25×7=175	1896	4739
4 „ light (2-horse)	11	6	15	.	9	4	9	1×7=7	61	152 5
4 „ medium „	36	41	50	.	22	42	36	3×7=21	248	744
4 „ heavy „	31	47	41	.	48	53	36	2×7=14	270	1890
Horses (led or ridden)	10	5	11	3	8	11	6	10×7×70	124	74 4
Hand carts and barrows	63	62	91	39	41	59	70	20×7=140	495	49 5
									5814	9175·1

Total, tons per day	1310 7
„ tons per hour	54 6
„ tons per yard width	5·6

was an indication that if the stone had been reduced to a size that would not be fractured by surface contact of traffic, it would have lasted satisfactorily The granite macadam, however, did not fracture, but in a large number of small areas it seemed as if it was disintegrating, and small stones could be easily picked out. It was, however, left in this state during the winter, and when the summer arrived again these places were not apparent; they had reamalgamated with the bitumen remaining in the immediate neighbourhood of these stones, and the surface became more or less even again in an extraordinary manner. This phase of disintegration and subsequent amalgamation went on for over two years, but eventually the bitumen failed to act and the pavement had to be dealt with.

Bitumen not at fault.—In other roads where the same class of bitumen had been used in a different manner with fine material the road had lasted fifteen to eighteen years; it was evident, then, that the bitumen was not at fault, but that it was the structure or the amount of bitumen.

In the structure there was only about 8 per cent. of bitumen, but when the material was laid there seemed to be more than was necessary It was a very rich mixture, and when tamped it was evidently in excess. It was noticed and commented upon at the time that when the roller passed over it in its hot state, the mass seemed to act as if it was a voidless structure—it rose in front and at the sides of the wheels; when it cooled, however, this was not apparent, which seemed to demonstrate that the bitumen when hot was in a very expanded state and that it contracted on cooling.

Expansion and Contraction of Bitumen.--The writer therefore tested the bitumen for expansion and contraction, and found it equivalent to $\frac{1}{300}$ of its bulk for every 10° F. increase of temperature.

After taking into consideration the atmospheric conditions that the pavement was subjected to, it was not difficult to arrive at the conclusion that this was the cause of the failure of the bituminous macadam form of construction. A difference of 82° F. has been noted in one day's temperature, and this would account for a very considerable expansion or contraction. With only 8 per cent. of bitumen in the structure it ought not to have affected it adversely, but when allowing for the different specific gravities of the aggregate, this percentage of bitumen by weight was found to be equal to 21 per cent. by volume. As the stones were 2 inches deep, and the bitumen would be affected to that depth by any weight on a particular stone, the expansion would be a serious item.

As will be seen later, the thickness of the film of bitumen would not be more than $\frac{1}{300}$ inch; the bitumen would be therefore subjected to a ductile force equivalent to several times its own thickness. The ductility of bitumen does not generally allow for so great a strain as this

without breaking, therefore the bitumen would be fractured if the traffic passed over the stone under such conditions, and as the bitumen would not necessarily combine, moisture would penetrate and cause eventual trouble.

Size of Stone in Wearing Surface.—It is submitted therefore that, where bitumen is to be employed in a surface structure submitting to heavy traffic, no particle should be in the surface larger than $\frac{5}{16}$ to $\frac{1}{4}$ inch, and any surface structure which contains larger material should only be used in roads where the traffic is limited, or confined to those places where the temperature varies within small limits.

It was for these reasons that a wearing surface consisting wholly of fine material and bitumen was used to take the place of the material that had been used in the trials, this surfacing being placed on the top of the bituminous macadam which had been removed, reheated, and placed in position to a depth of about 2½ inches, thus forming what has been called a two-coat pavement, one coat forming the base for the wearing-surface coating.

Analysis by Weight and Volume.—In a preceding paragraph mention is made of the percentage by weight and volume. In asphalt pavements it is recognised that a good deal of attention must be given to the analysis of the composition in regard to the amount of bitumen as compared with the aggregate, and all analyses are made by weight. Probably no two cases where these comparisons are made have the constituents of the same specific gravity. The specific gravity of the materials may vary between 0·4 and 3, the former being vegetable fibre and the latter being cement. Where ordinary stone is employed the specific gravity may vary between 2·4 and 3 The specific gravity of bitumen is about 1·06. It is obvious that if 10 per cent. bitumen is placed in two compositions which are respectively 90 per cent. with a specific gravity of 2·4, and 90 per cent. with a specific gravity of 3, the actual amount of bitumen is less in the one than in the other, although the size of the stone may be precisely the same in both cases; *e.g.* A, suppose 90 lbs. of material of specific gravity 2·4 of a fixed size requires 10 lbs. of bitumen to properly coat it, then the volume is represented as follows:—

$$\text{Material} = 37{\cdot}5 = 80 \text{ per cent. volume}$$
$$\text{Bitumen} = \frac{9{\cdot}43}{46{\cdot}93} = 20 \quad ,, \quad ,,$$

B, 90 lbs. of material, specific gravity 3, of the same fixed size as in A, is coated with 10 lbs. of bitumen; here the volume is represented as follows:—

$$\text{Material} = 30{\cdot}0 = 76 \text{ per cent. volume}$$
$$\text{Bitumen} = 9{\cdot}43 = 24 \quad ,, \quad ,,$$

The difference is equal to 4 per cent. of the volume; that is, there is 20 per cent. more bitumen in B than in A, and this may be of importance because it indicates that if A failed, B would not necessarily do so from a shortage of bitumen, whereas it might be assumed that B did not fail because the material was of a better character. It is evident, therefore, that wrong assumptions may be easily arrived at by making comparisons from an examination of the weight analyses only.

Amount of Bitumen to be used in Mixtures.—Having regard to the factors that have been raised in the foregoing, it is important to have some method which will enable the amount of bitumen to be determined that should be employed in a bituminous structure suitable for a wearing surface. The following explanation of an examination into the structures which have been laid down in this country will be found to be of interest, as from it can be formed a clear specification which, provided the bitumen is satisfactory, should prove suitable under conditions which apply in the British Isles. Where temperatures are higher, probably it will be found that the film of bitumen need not be so thick. In cold climates the thickness might have to be increased.

A series of calculations of the surface area of particles was first made, and in order not to confuse the matter each particle was assumed to be a cube. The particles are not cubes, but whatever the actual surface area may be, it is probably the case that the surface area of a cube multiplied by a constant will give the true surface area, because the results of the comparisons of various pavements show that the method adopted is satisfactory.

TABLE XXIX.—40 PER CENT. VOIDS.

200 mesh=0·08 mm. has a surface area	13,728 sq. ft.	
100 " =0·13 " " " "	8,446 "	
80 " =0·20 " " " "	5,490 "	
50 " =0·26 " " " "	4,224 "	
40 " =0·40 " " " "	2,745 "	
30 " =0·58 " " " "	1,892 "	
20 " =0·84 " " " "	1,307 "	
10 " =1·50 " " " "	732 "	
¼-in. chippings	513 "	(172)[1]
½-in "	355 "	(86)[1]
¾-in. "	177 "	(57)[1]
1-in. "	166 "	(43)[1]
1½-in. stone	212 "	(28)[1]

[1] The figures in brackets are the superficial areas if the stones were cubes, but the 1¼-inch chippings, etc., are not cubes but of greatly varying shapes, and the areas given without brackets are the calculated areas based on the amount of bitumen that was required to cover them in the same proportion as would be necessary in the foregoing sizes of material of this table. The excess is due to the minute corrugations and rough faces of the fractures of the stones.

Then, taking three analyses which are fairly representative of two rock asphalts, A and B, that are successfully used in London, and one artificial asphalt, C, out of a series of tests.

Areas as calculated from Table I.:

A = 9370 sq. ft.	Sp. gr. of aggregate 2·65.	Sp. gr. of bitumen 1·06
B = 11319 ,,	,, ,, 2·65	,, ,, 1·06
C = 5846 ,,	,, ,, 2·72	,, ,, 1·06

Therefore specific gravity of A as a mass = 2·477

,, ,, B ,, = 2·43

,, ,, C ,, = 2·58

$$A\quad \frac{2{\cdot}477\times 10{\cdot}87\times 12}{1{\cdot}06\times 9370\times 100}=\cdot000325=\text{thickness of film.}$$

$$B\quad \frac{2{\cdot}43\times 13{\cdot}62\times 12}{1{\cdot}06\times 11319\times 100}=\cdot000331=\quad ,,\quad ,,$$

$$C\quad \frac{2{\cdot}58\times 13{\cdot}45\times 12}{1{\cdot}06\times 5846\times 100}=\cdot00065=\quad ,,\quad ,,$$

Formula for calculating thickness of film from an analysis:—

a=area of faces of all grades in square feet.

s=specific gravity of mass of mixture of bitumen and aggregate.

b=percentage of bitumen in mixture.

1·06=specific gravity of bitumen.

$$\text{Thickness of film}=\frac{s\times b\times 12}{1{\cdot}06\times a\times 100}.$$

TABLE XXX.

	A.	B.	C.
Bitumen . . .	10·67	13·62	13·45
Passes 200 mesh .	51·85	75·54	14 86
,, 100 ,, .	16 73	7·33	16·25
,, 80 ,, .	7 25	1 26	10·07
,, 50 ,, .	3·70	0·54	34·54
,, 40 ,, .	..	..	1 88
,, 30 ,, .	8·04	1·01	2 50
,, 20 ,, .	1·04	0·31	..
,, 10 ,, .	0 61	0 15	1·37

Allowing for the difference in specific gravity of the mineral matter in each case, the film which covered each particle was A=0·000325, B=0·000331, and C=0·00065.

This indicates that the coating of the natural rock is much more

effective and less wasteful in bitumen than it is possible to employ in artificially made asphalts to the extent of 100 per cent.; in other words, we use in artificial mixtures just twice the amount that nature employs in the natural rock which is used for the same purpose.

Numerous examples have been tested, and they all follow the same lines and give approximately similar results. This being the case, it is not difficult to formulate a table which will denote the amount of bitumen required in any grade of material that may be selected as a structure.

TABLE XXXI.—PERCENTAGE OF WEIGHTS OF BITUMEN REQUIRED TO COAT 1 CUBIC FOOT.

Material.	200 Mesh	100 Mesh.	80 Mesh.	50 Mesh	40 Mesh	30 Mesh	20 Mesh	10 Mesh
Sp. gr 1 0 .	84 90	52 2	33 92	26·10	16 96	11·68	8 08	4 52
„ „ 3 0 .	28 30	17 4	11 31	8 70	5 65	3 68	2 69	1 51
„ „ 2 82 .	30 11	18 55	12 05	9 27	6 01	4·14	2 87	1 60
„ „ 2 65 .	32 04	19·69	12 80	9 86	6 41	4 41	3 25	1·70

From a table built up on lines that are here indicated it is possible to compare the effect of bitumen on materials, and it would enable engineers who have before them a successful and unsuccessful pavement in the same area, to inform themselves whether the bitumen is of the same thickness per superficial area coated in the one case as the other.

Examples of Effect of Grading on Amount of Bitumen.—For example, suppose that the materials in two examples are the same specific gravity but of different grading, but that the percentage of bitumen by weight was the same in both instances.

TABLE XXXII.

	A		B.	
	per cent.		per cent.	
Bitumen . .	12	..	12	..
200 mesh .	15	4·80	25	8·01
100 „ . .	15	2 96	18	3 54
80 „ . .	8	1 02	12	1 54
50 „	20	1·97	10	0·98
40 „ .	15	0 96	5	0 32
30 „ .	8	0·36	4	0·18
20 „ .	4	0 13	7	0 23
10 „ . .	3	0·05	7	0·12
	100	12 15	100	14·92

It will be seen by taking the specific gravity as 2·65 for the mineral matter and multiplying the percentages in the analysis by the figures in the table for the various meshes at a specific gravity of 2·65, that the percentage of bitumen in A is very nearly the amount that is found to be necessary in an artificially manufactured asphalt, but in the example B there is a shortage of 2·92 (or about 25 per cent. short of the required amount of bitumen). In other words, the thickness of the film in A is approximately 0 00064 inch, whereas in B it is only 0·00051 inch. In consequence we can judge that if A was successful and B was unsuccessful one of the reasons of failure could be attributed to a shortage of bitumen, and that therefore it is plainly evident that a superficial examination of the weight analyses of asphalt mixtures is not a guide to a true examination, and it will be seen that every phase of grading, volume, and specific gravity must be considered before a comparison is made.

Amount of Bitumen in Natural Asphalt.—It must not be taken that the writer is laying it down as a rule that the film should be of the thickness set forth. Natural rock asphalt has a film of bitumen thickness only half that of the artificially manufactured asphalts. It is probable that by improved machinery or methods of mixing it may be that the percentage of bitumen in the artificial asphalts can be brought to that of the natural rock. This is well worth investigation, because the cost of the bitumen in the artificial mixture is equivalent to about 66 per cent. of the cost of the mixture, and a reduction would materially alter the cost of the mixture, and roads would be in that respect greatly cheapened in cost. The possibilities of such a result eventuating are not remote; the results of manufacturing cement concrete bricks as described on page 216 are sufficient to indicate that as it is possible to use half the amount of cement in cement concrete and obtain equal results to what are obtainable with double the quantity, it may be equally possible with bitumen, and especially as in this case it is done by nature.

The writer is convinced that the above tables can be used in the same direction and with similar results in cement concrete, the cement being taken as occupying the relative position of the bitumen in asphalt.

Voidless Structures.—Another experimental series took the form of voidless structures artificially made. A measure exactly 1 foot in every direction—length, breadth, and depth—was used, and filled with variously graded materials It was filled first with 1½-inch granite and the weight was 97 lbs., equal to 55 per cent. cubic feet of granite, or 45 per cent. voids. But the 97 lbs was removed, and into the spaces were inserted 28 lbs. of ⅛-inch chippings, 29 lbs. of fine sand, and 7 lbs. of cement; the total weight was 161 lbs.

The volume represented by these was respectively 55·0 per cent., 5 3 per cent., 17·3 per cent., and 3·6 per cent., or a total of 91·2 per ent.; *i.e.* 8·8 per cent voids. Similarly with ½-inch chippings, 97 lbs., he spaces were filled with 33 lbs. and 8 lbs. cement, the total weight eing 138 lbs., and the voids=21 per cent. Using granite dust, *i.e.* ⅛ o powder, the weight was 116 lbs., to which 14 lbs. of sand and 5 lbs. f cement was added=135 lbs. The voids in this case were 23·6 per cent.

The smaller the aggregate the greater the voids; it is clear that the ifficulty is to place the particles in the voids that remain among the maller particles.

It is evident that in the three cases illustrated a perfectly voidless tructure would be secured by the addition of bitumen to the amount f volume of the voids represented in each case, *i.e.* 8·8 per cent., 21 per ent., and 23·6 per cent.

By the table above, the amount of bitumen necessary to coat each article is 3·6 per cent. or 8 8 per cent, of the volume in the first case, *.e*, just the amount required to fill the voids; 10·8 per cent. in the econd case, *i.e.* 10·2 per cent. less than the percentage of voids; and n the third case 13·50 per cent., or 10 10 per cent less than the ercentage of voids.

Even supposing that such percentages of bitumen could be coated n to the particles, it would not make a satisfactory structure, the mass vould be easily crumbled, this would be apparent if a sample was made, nd it would be clear that if the Table A was used without taking into onsideration the factors necessary for a good structure, it would be nisleading. In the case of the first of the last three examples, the full uantity of 8·0 per cent. by weight is necessary to make a good conrete which is useful both for the surface of a lightly trafficked road uch as would be found in the side streets of any town; but it makes n excellent and economical base of a "two-coat" pavement, even if a very heavy tar mixture is used of the same consistency as the bitumen hat is generally adopted as suitable for the upper surface. It is imrobable, in the case of the voids being filled in the other two examples, hat the composition would hold together under traffic for any length f time, so that the mere formation of a structure which has for its bject a voidless mass must not be taken as providing a good road tructure; but, on the other hand, it must not be assumed that a voidess structure differently composed would be a failure Mastic asphalt s voidless except perhaps for the enclosed spaces which are formed by he gases contained in the substance while in a hot condition, and which n cooling contract and become liquid again, leaving these enclosed paces, thus forming in each case a number of miniature voids.

Fine Material Important in Mixture.—From the previous examination of the "colloid" theory in bitumen, we may suggest that as fine material is important in the bitumen, so also is fine material of the highest importance in the structure in which the bitumen is to be employed. The bitumen must be conveyed and brought into contact with every particle forming the aggregate, and although in theory this would be secured by making a voidless structure, it is practically impossible to construct and lay down a voidless structure in a road with a material in which bitumen is to be employed The temperature of the composition when it is being laid is 325° to 400° F. It has been explained that when it is in a hot condition the bitumen is in an expanded state. If it is rolled when in a hot state, the surface thereby is sealed. Any person passing by can smell the peculiar odour which comes from the bitumen. This at once informs us that certain parts of the bitumen are in a volatilised state; and if this is so from the surface, these gases must be formed in the structure itself, as the bitumen contracts when cooling. After the rolling has stopped, the contraction will cause spaces to form in the structure

Voids in Compressed Asphalt.—An examination of a section of cold asphalt taken from the road will indicate that whatever compression has been given by tamping or rolling, the compression is very much more distinct near the surface and very indistinct at the underside of the sheet of asphalt. Microscopically examined, it has been estimated that the compression at the surface is full, but at the underside is equal to 85 per cent. Thus the average percentage of voids is 7½ per cent.

Whether it is this that causes the necessity of providing a larger quantity of fine material to be used, it would be difficult to say, but there remains the fact that in every instance of a good and lasting asphalt pavement the amount of fine impalpable material is very considerable.

Take the two examples of natural rock asphalt that are given on page 189. The percentage of fine material of 80, 100, and 200 mesh is very high: in A it is 75·83; in B it is 84·13 per cent.; in C, an artificially made asphalt, it is 47·18 per cent.

In all the examples of paving which have given a satisfactory surface lasting over ten years under heavy traffic, the amount of dust which it is apparent should be included in the mixture is at least 35 per cent., and not less than ½ of this percentage is of 200 mesh or less size. There are some successful cases where there is an excess of bitumen, in which case the bitumen takes the place of the dust and it becomes a mastic as distinct from an asphalt.

Proportion of Grading.—The rule that the writer suggests should be adhered to is that the aggregate in a wearing surface should consist of a composition of grading somewhat on the following lines:—two-fifths should be of 200, 100, and 80 mesh, the greater proportion being of 200 mesh; two-fifths of 50 and 40 mesh; and the grades 30, 20, 10 and below 10 one-fifth; the largest size of material not to exceed ¼ inch

Film Thickness.—The film of bitumen should be 0·00065 inch thick.

Test with Tar.—In order to find whether the filling of the bitumen had any material benefit, a test was made with tar, which was liberally treated with a finely divided filler. When this was properly incorporated, an asphalt-wearing surface was made of similar mixture and grading to C on page 189, but instead of bitumen the treated tar was used. Although the result was not as good as that obtained from the bituminous mixture, it was surprisingly better than was ever anticipated, and submitted to heavy traffic for several years

Expansion and Contraction of Bitumen.—The road is subjected to weather, varying temperatures, a variety of traffic, and varying intensity of traffic; it may be fairly conjectured, then, that it is the expansion and contraction of the bitumen that is the main cause of its failure in many of those instances where failure has occurred. These failures will be reduced by providing such an amount of fine material that the bitumen is brought into multitudinous contact by such small particles that, although the expansion of the bitumen takes place, the effect is very small and the traffic cannot disturb it to any material degree. Another method is to use a harder bitumen not so easily affected by the temperatures of the atmosphere; but in this case the bitumen must be in excess, and will form an asphalt more in the form of what is known as mastic asphalt.

Success obtained from proper Grading.—In the writer's opinion these are, with the grading of the aggregate, the main factors which will go far to ensure success for a paving in which bitumen is used as a binding agent.

Clinker Refuse from Destructor.—In 1903, for the purposes of making a quantity of paving slabs with clinker refuse from the destructor, a plant was installed which consisted of a crusher which roughly crushed the clinker and then, passing through a screen, fell into a second screen in which was a paddle lift which carried all the material that failed to pass this screen to a granulator which ground the clinker until it was able to pass the screen. By this means the following grading was secured:—

Passing	200 mesh	10·3 per cent.
,,	100 ,,	5·5 ,,
,,	80 ,,	4·1 ,,
,,	50 ,,	10·6 ,,
,,	30 ,,	26·5 ,,
,,	20 ,,	6·1 ,,
,,	10 ,,	28·3 ,,
on	10 ,,	5·6 ,,
		100

This grading was near to that required for an asphalt-wearing surface. A number of small experimental areas were laid down composed of this material with the requisite amount of the finer grades in 1908 and following years and proved satisfactory.

There seems no reason why this material should not be more extensively used where it is available and where fine sand is not obtainable. The difficulty that had to be overcome was keeping the fine material that is already in the aggregate in the mixture. The aggregate had to be heated to about 600° F., and these fine particles did not pass through the heater at the same pace as the larger of the small particles, and a proportion was lost or floated in the chamber and found its way into the flues, from which it had to be extracted and added to the composition; whereas, in the ordinary method of using sand and cement, the cement which is 200 mesh is added at the mixer, and hence it is always known that there is the required quantity of impalpable powder in each batch mixed. This is a difficulty which can be got over by special machinery whenever it is intended to use this class of material.

Dust from Granite Roads.—From granite macadam roads the mud and sweepings (apart from the manure and vegetable matter), when dried and sifted, indicate that in this material a good grading can be secured. The analysis is as follows:—

Passing	200 mesh	23 per cent.
,,	100 ,,	9 ,,
,,	80 ,,	8 ,,
,,	50 ,,	5 ,,
,,	30 ,,	30 ,,
,,	20 ,,	10 ,,
,,	10 ,,	15 ,,
		100

Wood Flour.—When the fine material of 200 mesh is difficult to obtain, cement is always available, not for its cementing properties but merely on account of its fine grading The cement is in some places very expensive, whereas a material like wood flour may be available; and as the specific gravity is about $\frac{1}{6}$ that of cement, its bulk is six times as great as cement, and it may therefore be much less costly for a filler.

An analysis of a sample that was submitted showed :—

Passing 200 mesh	19·1	per cent.
,, 100 ,,	19 0	,,
,, 80 ,,	19·1	,,
,, 50 ,,	23 8	,,
,, 30 ,,	19·0	,,
	100·0	

This material might be more successfully employed in the manufacture of asphalt blocks rather than in an *in situ* pavement, because the wood fails to retain heat long enough to enable it to be carted any distance from the mixing works, and hence it will be so cold when it arrives at the site that difficulty is experienced in laying it in position.

The foregoing Tables are used in the Examination of the following Road Sections.—A few examples of analyses of various pavements that have been laid down by different firms in the British Isles will perhaps be instructive of the bitumen contents and films as worked out from the methods suggested in this chapter :—

Example A.

Bitumen	10·37	per cent.
200 mesh	1·97	,,
100 ,,	5·03	,,
80 ,,	4·77	,,
50 ,,	34 50	,,
40 ,,	11·20	,,
30 ,,	8·15	,,
20 ,,	8·65	,,
10 ,,	11·88	,,
on 10 ,,	3·48	,,
	100 00	

The surface area=3095 superficial feet and the thickness of film of bitumen=0 00115.

Example B

Bitumen	15·94 per cent
200 mesh	6 43 ,,
100 ,,	27·43 ,,
80 ,,	1·78 ,,
50 ,,	11·77 ,,
40 ,,	10 29 ,,
30 ,,	8·31 ,,
20 ,,	7 63 ,,
10 ,,	6·42 ,,
on 10 ,,	1·00 ,,
	100·00

In this case the area=4565 superficial feet and the film of bitumen= 0·00068 inch.

Example C.

Bitumen	13·35 per cent.
200 mesh	14·40 ,,
100 ,,	15·19 ,,
80 ,,	17·24 ,,
50 ,,	33·05 ,,
40 ,,	2·00 ,,
30 ,,	2·16 ,,
20 ,,	1·25 ,,
10 ,,	1·36 ,,
	100·00

The areas are 6282 superficial feet and the film is 0·00065 inch thick.

Another sample with local material is as follows:—

	Example D.	*Example E.*
Bitumen	11 82 per cent.	14·6 per cent.
200 mesh	18·85 ,,	15·6 ,,
100 ,,	30·98 ,,	29·5 ,,
80 ,,	9·16 ,,	9·3 ,,
50 ,,	13·41 ,,	15·4 ,,
40 ,,	5·97 ,,	6·3 ,,
30 ,,	4·25 ,,	4·1 ,,
20 ,,	2·30 ,,	3·8 ,,
10 ,,	0·37 ,,	1·4 ,,
on 10 ,,	2·89 ,,	. .
	100·00	100·0

[he area of D is 6605 superficial feet and the film of bitumen=0·00058, ınd the thickness of film in E= 000651.

Another sample gives the following analysis. It was 1½ inch thick, aid on old macadam surface :—

	Example F.		*Example G*
Bitumen	14·156 per cent.		19·5 per cent.
200 mesh . .	14 144 ,,		17·05 ,,
100 ,,	6·08 ,,		6·05 ,,
80 ,, .	2·24 ,,		1·9 ,,
50 ,, .	4·68 ,,		5·55 ,,
40 ,, . .	3 80 ,,		4·57 ,,
30 ,,	3 80 ,,		4·53 ,,
20 ,, .	6 326 ,,		7·00 ,,
10 ,, .	15·874 ,,		15·4 ,,
8 ,, . .	7·89 ,,	on 10	18·00 ,,
4 ,, . .	21·01 ,,		..
	100·00		100·00

'he surface area F=3326 square feet and the film was 00130 inch.
,, ,, G=3732 ,, ,, ,, ·00151 ,,

The samples H and K were taken in 1916 and 1917, with the following nalysis :—

	Example H.	*Example K.*
Bitumen . .	12·03 per cent.	11·1 per cent.
200 mesh . .	15·28 ,,	13·6 ,,
100 ,, . .	16·04 ,,	5·1 ,,
80 ,, . .	25·71 ,,	5·6 ,,
50 ,, . .	12·77 ,,	36·4 ,,
30 ,, . .	7·53 ,,	18·45 ,,
20 ,, . .	0·45 ,,	3 3 ,,
10 ,, . .	1·48 ,,	2·55 ,,
on 10 ,, . .	8·71 ,,	3 05 ,,
	..	0·85 ,,
	100·00	100·00

he superficial area of H=5607 square feet and the film=0·00065 ıch; that of K works out at ·000682.

Two examples of a special character laid down as an experiment, ¼ inches thick, on old macadam :—

	Example L.	*Example M.*
Bitumen . .	11·85 per cent.	11·00 per cent.
200 mesh . .	13·78 ,,	18·20 ,,
100 ,, . .	7·02 ,,	9·85 ,,
80 ,, . .	8·40 ,,	4·15 ,,
50 ,, . .	19·90 ,,	12·00 ,,
40 ,, . .	3·90 ,,	4·90 ,,
30 ,, . .	4·53 ,,	6·00 ,,
10 ,, . .	21·54 ,,	15·15 ,,
on 10 ,, . .	9·08 ,,	18·75 ,,
	100·00	100·00

The superficial areas are 4211 superficial feet and 1556 superficial feet respectively, and the film thicknesses are respectively 0·00085 inch and 0·00076 inch.

Comments.—The comments that can be made from an examination of the analyses are as follows :—

A The mixture would be rich in bitumen, there being nearly 80 per cent. more bitumen in the mixture than is necessary to coat the particles. Owing to the low percentage of fine material, the excess of bitumen does not make up for its lack of fine material.

B. There is the right quantity of bitumen in this mixture, and not an unsatisfactory proportion of fine material; but it is too high in the 100 mesh, and there is too large a proportion of the coarser grading.

C is a good and evenly divided grading. There seems to be, if a criticism is needed, a trifle too high a percentage in the 80 mesh which might with advantage be given to the 30 and 20 meshes. The film of bitumen is satisfactory.

D. There is too high a proportion of fine material and a shortage of bitumen. This is an example which indicates that, in all probability, if the 100 mesh had been reduced and the difference given to the 50 and 30 meshes, the same percentage of bitumen would have been more satisfactory both as regards the film thickness and the grading.

E is a satisfactory mixture.

F and G. These samples from the same pavement show very uneven mixing. The percentage of bitumen is very high, and it was known to be of a hard consistency. It is a mastic asphalt.

H is a mixture which is badly graded; there is too much fine material, although the film thickness is satisfactory.

K is short of fine material, but there is a slight excess of bitumen, which is helpful.

L and M These are both rich in bitumen. There is not enough bitumen to justify it being called a mastic asphalt, although it is approaching that point. They are short of fine material, but the excess of bitumen makes up for that to a great extent.

This form of analysis is useful for determining, as has already been mentioned, whether the amount of bitumen that is required to coat the particles is really in a structure that has failed. Take three instances which are instructive: one was laid in King's Road, London, in 1894; the second was in King's Road, London, in 1896; and the third in the Thames Embankment, 1906.

	1.	2.	3.
Bitumen .	10·0 per cent.	10·8 per cent.	11·5 per cent.
Passing 200 mesh	7·4 ,,	13·6 ,,	17·5 ,,
,, 100 ,, .	15·9 ,,	7·3 ,,	7 0 ,,
,, 80 ,, .	11·4 ,,	22·5 ,,	23·0 ,,
,, 50 ,, .	11·1 ,,	25·5 ,,	32 0 ,,
,, 40 ,, .	24·0 ,,	8·9 ,,	6·0 ,,
,, 30 ,, .	12·2 ,,	6·6 ,,	3·0 ,,
,, 20 ,,	5·0 ,,	3·0 ,,	0·0 ,,
,, 10 ,, .	3·0 ,,	1·8 ,,	0·0 ,,
	100·0	100·0	100·0

The percentage of bitumen worked out on the scale above should be 9·8, 11·62, and 11·04 respectively, showing that there was sufficient bitumen in Nos. 1 and 3, but a shortage in No. 2. Of the three No. 1 failed, as the composition scaled under the heavy traffic; No. 2 resisted fairly satisfactorily, but required considerable maintenance; No. 3 has been quite successful. The results indicate that the amount of fine material was insufficient in No. 1, although for the composition the particles were well coated with bitumen; the quantity of bitumen was not sufficient to make up for the deficiency in fine material. In No. 2 the fine material was more in evidence, but the shortage of bitumen undoubtedly caused its non-success. No. 3 is more plentifully supplied both with filler and bitumen, and hence its success.

The difficulties that the road engineer has to contend against in forming a properly graded pavement are more easily understood when one considers how these gradings are to be obtained. In the example of the clinker that is ground from large material, the analysis of which is given on page 195, there is to hand quite a good mineral aggregate which obviously can be ground to the required mesh sizes. But a sand that is

locally obtainable may have a very inferior grading, and only by careful mixing of various sands, that may be found in or near the district, can the satisfactory grading be secured. Doubtless in the examples given above the variation of the grading is wholly due to the quality of sand available in the districts where the pavement was laid.

A good grading has been obtained from granite dust as it comes from the screens at the quarries, a fine local sand and a proportion of cement. Taking the cement as wholly of 200-mesh material —

Fine Sand.			Granite Dust.		
Passing	100 mesh	4 per cent.	Passing	100 mesh	5 per cent.
,,	50 ,,	42 ,,	,,	50 ,,	12 ,,
on	50 ,,	54 ,,	,,	20 ,,	27 ,,
			,,	10 ,,	29 ,,
			on	10 ,,	27 ,,
		100			100

Flue dust gives the following analyses :—

Passing	200 mesh	48·15 per cent.
,,	100 ,,	20·87 ,,
,,	80 ,,	11·47 ,,
,,	50 ,,	4·16 ,,
,,	30 ,,	10·86 ,,
,,	20 ,,	1·23 ,,
,,	10 ,,	2·07 ,,
on	.. ,,	1·19 ,,
		100·00

The following samples of sands were submitted to the writer, and the following are the gradings :—

	No. 1.	No. 2.	No. 3.	No. 4.
Passing 200 mesh	0 5	1·41	1·27	·57
,, 100 ,,	14·5	10 75	·80	1·00
,, 50 ,,	75·4	56·77	16·34	61 50
,, 20 ,,	9·6	31·07	65·50	25 10
,, 10 ,,	..	..	16 09	11·83
	100 00	100·00	100·00	100·00

The recommendation was 66 per cent. of No. 1 and 34 per cent. of No. 3, which would give—

Passing 200 mesh	.	0·78 per cent
,, 100 ,,		9·92 ,,
,, 50 ,,	.	55·91 ,,
,, 20 ,,	.	22·90 ,,
,, 10 ,,	. .	5·49 ,,
		100·00

FIG. 34.—For sand and stone, as well as for tar, pitch, and asphalt.

Selection of Sands.—The selection of the right kind of sand and its grading is of great importance, and requires very careful examination and continual analysis, as it may easily vary when obtained from the same source.

The above tests give the satisfaction that one can obtain by calculation without examination, but a good asphalt can be more satisfactorily judged by the appearance of the composition to those skilled in its examination. But what is of considerable importance as an aid to this physical examination is the "pat-paper" test

Pat-Paper Test.—This consists of taking a large piece of paper and laying it on a flat surface, then a quantity of the hot mixture is taken from the mixer and placed in the centre of the paper. One edge of the paper is drawn over to meet the opposite edge, thus enclosing a quantity of the mixed material. This enclosed material is then pressed to obtain a flat surface; the paper is turned back and the bituminous material removed; the paper is stained by the hot bitumen, and the density of this stain gives the observer the information as to whether the quantity of bitumen is short or in excess of the desired amount.

Plate I shows a mixture short of bitumen.
,, II. ,, ,, with the requisite quantity of bitumen.
,, III. ,, ,, with an excess of bitumen.

Laboratory.—The engineer who has charge of the construction of roads will find that it is necessary to have a laboratory for making analyses and tests of road materials. The apparatus that is required is not of a very expensive character, but should be the best of their respective kinds.

The following are necessary:—Penetrometer, chemical balance, bunsen burner, specific-gravity measures, scales, oven, crucibles,

Plate I.

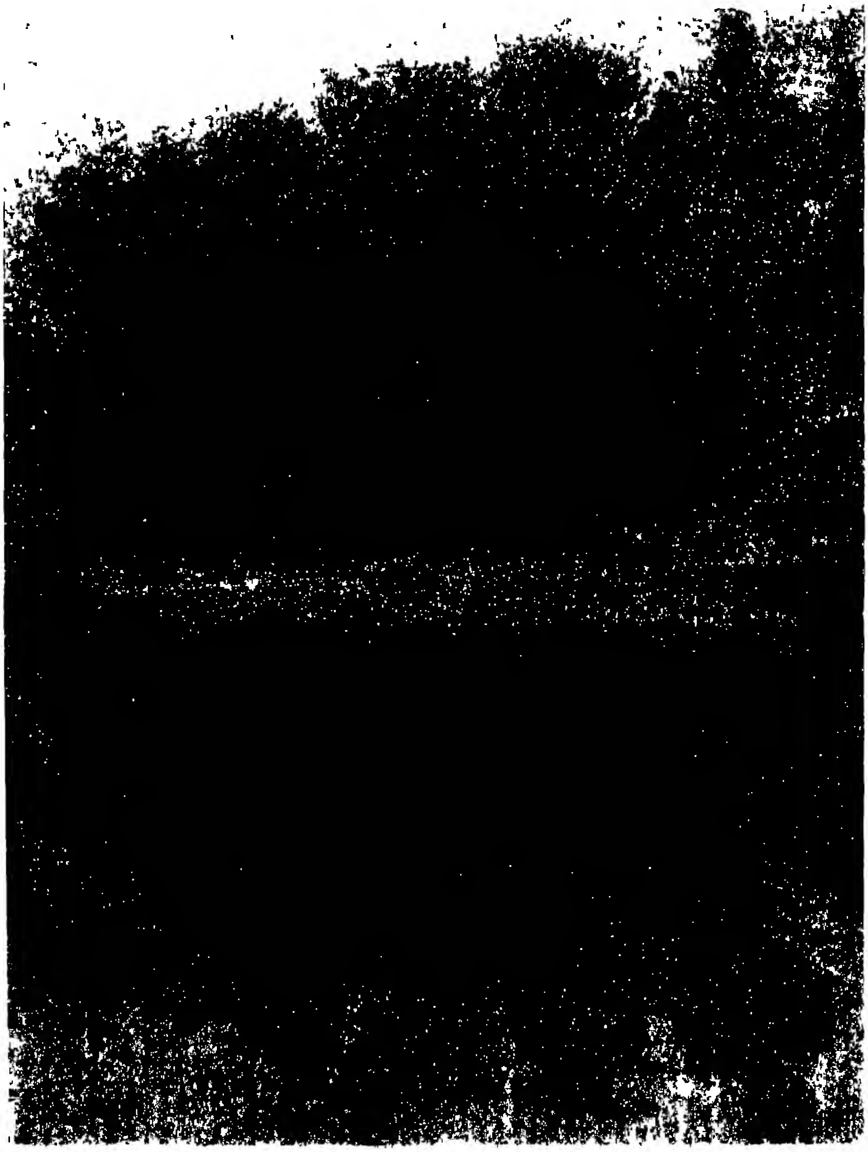


PLATE II.

[*To face p.* 202.

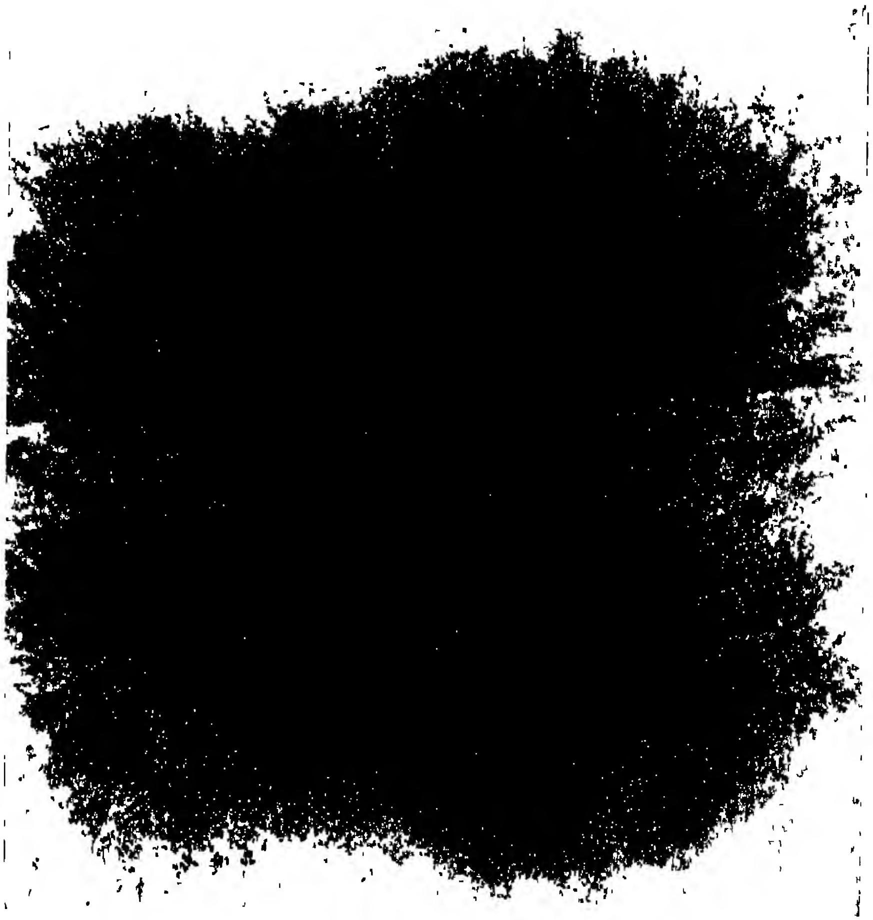


PLATE III.

flasks, retorts, etc., a supply of water and gas, a stink cupboard, tables, and desks.

Suitable instruments such as thermometers, etc., can be obtained from The Hutchinson Testing Apparatus, Ltd., 11 Tothill Street, Westminster, which firm has made a speciality of this class of work for road purposes.

The type of thermometer for testing the temperature of tar or bitumen in tanks is shown in fig. 34.

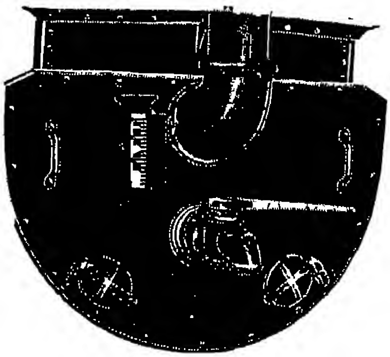


FIG. 35.—Thermometer fixed on a tar boiler.

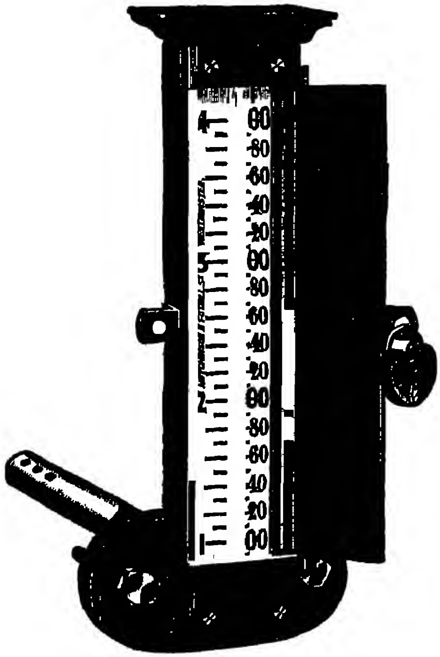


FIG. 36.

Figs. 35 and 36 show a thermometer to be attached to a tar boiler.

Fig. 37 shows the type of specific-gravity gauge.

Fig. 38 is a viscosity and consistency gauge. A standard viscosimeter will show whether a sample of tar is of the No. 1 or No. 2 grade of the Engineering Standards Committee, or whether a consignment differs fundamentally from an approved sample.

Fig. 39 shows a flash-point tester.

The hydrometer and temperature corrector illustrated in fig. 37 comply with the Road Board's definition of the apparatus for the proposed test. They are supplied together in a compact wood case, with a metal container and stirrer.

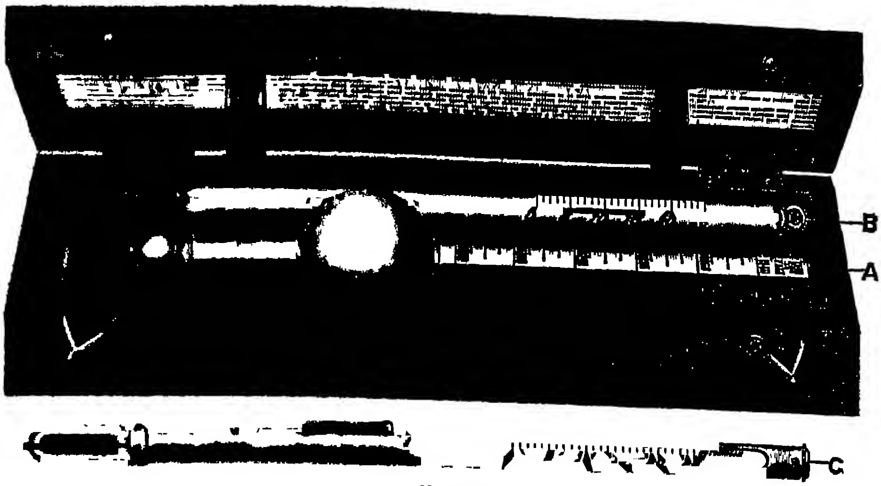


Fig. 37.

A, metallic hydrometer, graduated from 1·110 to 1·240; B, temperature corrector; C, temperature corrector in brass sheath, with special bulb guard and hook to suspend it in sample.

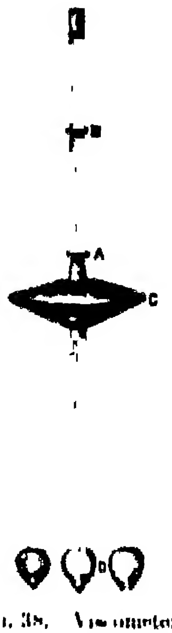


Fig. 38. Viscometer.

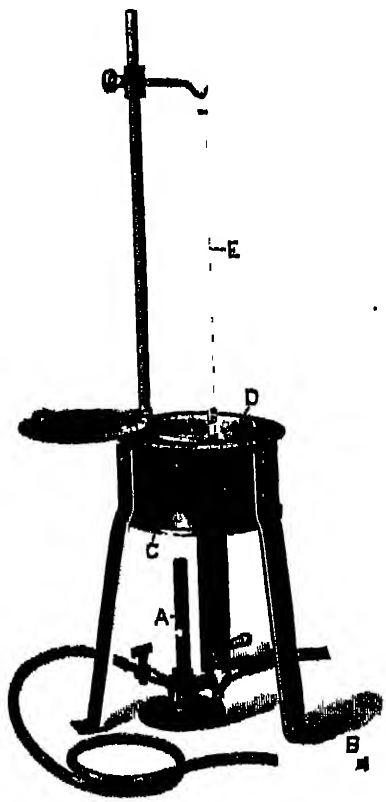


Fig. 39.—Hutchinson's flash-point tester for coal-tars, asphalts, and oils.

A, bunsen burner; B, capillary tube for testing flash; C, outer wall of air-bath; D, inner cup for substance under test; E, thermometer.

The utility of this machine is not confined to ascertaining the exact temperature at which the material under test becomes inflammable, and therefore dangerous, it also serves to distinguish crude substances from refined products ; with regard to the latter, it indicates the point to which distillation, or "cutting back" with light oil, has been carried.

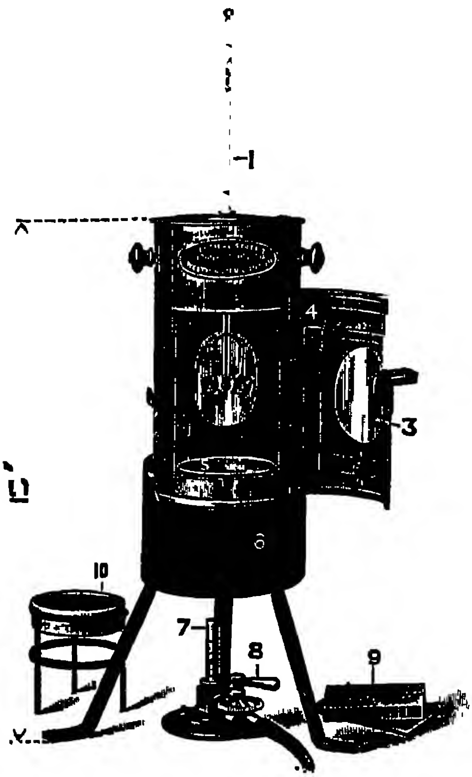


FIG. 40.

1, thermometer; 2, material under test; 3, mica window; 4, door; 5, removable pan; 6, iron stand; 7, luminous burner; 8, quadrant tap; 9, mould for half-inch cubes; 10, volatilisation dish and stand.

This test also affords a very handy and simple method of ascertaining whether it is safe to heat the material before use.

The instrument can also be used to ascertain if water is present in any tar, asphalt, or oil.

Fig. 40 shows the type of apparatus for determining the melting-point of tar, asphalt, and oil, and can be used for the volatilisation test.

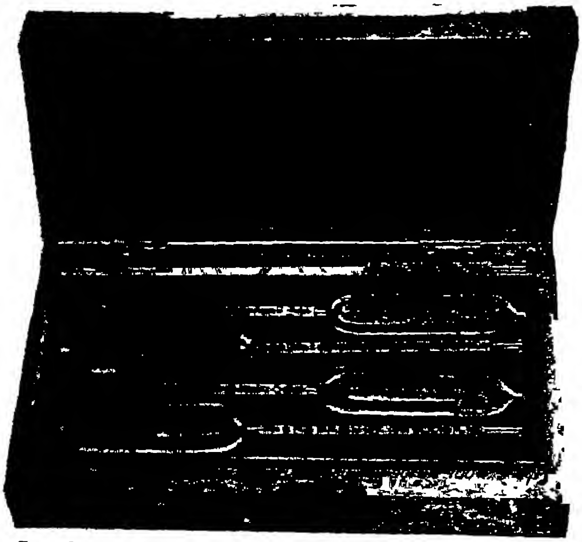


Fig. 41.—Specific gravity apparatus for use with road tars, asphalts, and oils.

Set of specific gravity hydrometers, comprising four instruments, marked at every ·001, the whole covering a range from 1·000 to 1·300. These instruments are mercury poised. Each set is furnished (in the case) with a small trial instrument which, on being immersed in the liquid, indicates the hydrometer to be used, also with a thermometer (Fahrenheit) graduated from 60° to 100° for use in the tests.

A metal hydrometer pot (with stirrer), to contain the liquid to be tested, accompanies each set.

Can also be supplied for use with oils lighter than water graduated from 0·700 to 1·000 at same price.

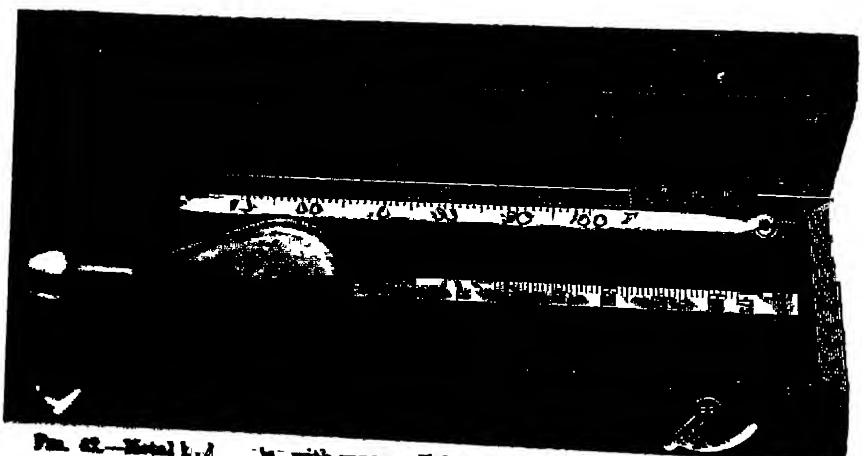


Fig. 42.—Metal hydrometer with range sufficient for practically all road tars. Graduated from 1·160 to 1·240.

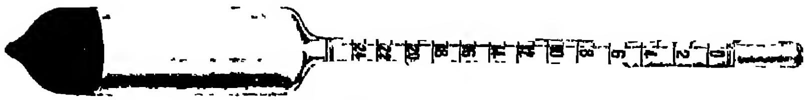


Fig. 43. Specific-gravity hydrometer (half actual size).

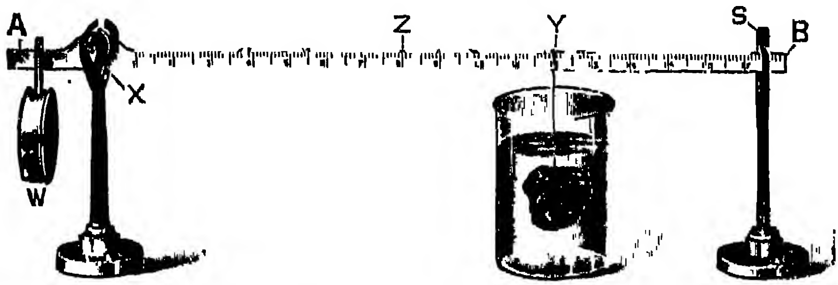


Fig. 44.—Specific-gravity balance for stone. (Walker principle.)

A knowledge of the specific gravity of road stone is necessary to the highway engineer, not only for the purpose of estimating the value of the material as based on that important property, but also to determine the area that can be covered by a given weight of stone and the amount of bituminous binder required for the aggregate.

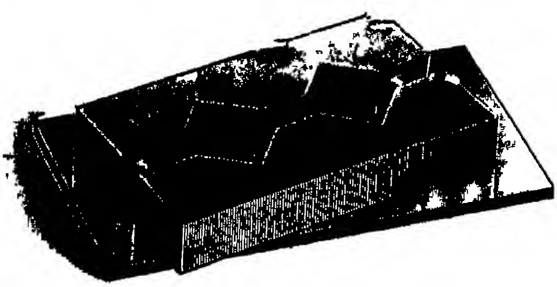


Fig. 45.—Brass mould for half-inch cubes.

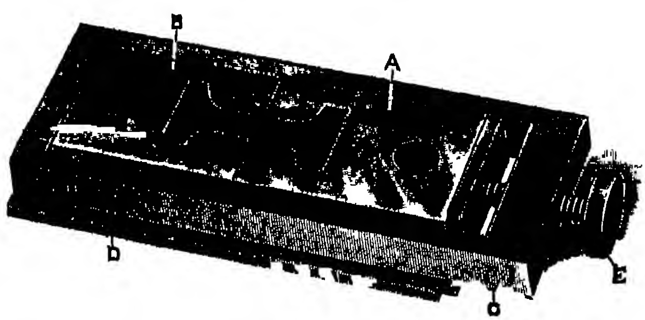


Fig. 46.—Mould for a ductility test, as originated by John A. Brodie, Esq., M.Inst.C.E., City Engineer of Liverpool.

A, top part of aluminium mould, with hole for suspension; B, bottom part of mould of a predetermined weight; C, brass frame; D, bottom plate; E, screw to enable mould to be removed from frame.

A glass jar of suitable dimensions for this important test accompanies the mould.

Flow Test. This is another method of testing the consistency. A cylinder of bitumen is made from a brass mould $\frac{3}{4}$ inch long $\frac{3}{8}$ inch diameter on a corrugated tray with undulations equal to the diameter of the cylinder. This tray is set at an angle of 15°, and it is gradually heated to a temperature at which the bitumen will flow.

The comparison of the length of the flow with a standard will indicate the relative consistency of the sample with that of the standard.

Penetrometer. The penetrometer is required to determine the consistency of the bitumen or tar that is to be used in the mixtures. There are several machines on the market, and the measure of the penetra-

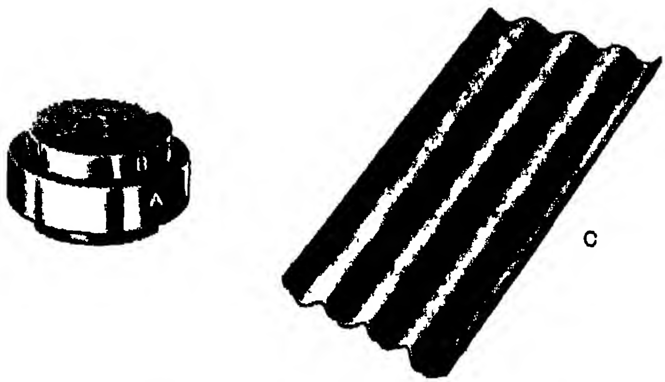


FIG. 17. Asphalt or pitch-flow plates and moulds: Professor Clifford Richardson's flow test.

A, ring for holding the split mould together; B, split mould; C, brass plate with corrugations corresponding in size to that of the moulded cylinder.

Two 6 corrugation plates and one mould, or three 4-corrugation plates and one mould, constitute a set.

tion of a No. 2 cambric needle weighted with 100 grms. at 77° F. in one second is in hundredths of a centimetre.

A sample of the bitumen fluxed ready for use is taken from the tank and placed in a small tin about 3 inch diameter and $\frac{1}{2}$ inch deep. The surface of the tar or bitumen should give a perfectly smooth, glossy, and even surface; there should be no air bubbles or oily appearance, which would indicate the presence of moisture or an imperfect mixture.

The tin and contents are then placed in water, which is brought to a temperature of 77° F.; and when it has been left in the water for a time sufficient to allow the whole of the contents to be brought to that temperature, it is placed under the needle so that the point is practically on the surface of the bitumen; the needle is then released for the period of one second, and the difference between the first and second positions of the finger on the dial will give the penetration at that temperature.

Analysis of a Paving Mixture.—A sample of the asphalt is taken from the surface of the road and marked with the date, a number, and the place from which it was taken; the number should be a duplicate of a page number in a reference book, on which page is fully described the analysis and comments. Each sample should have its place in a cupboard and be kept for future reference.

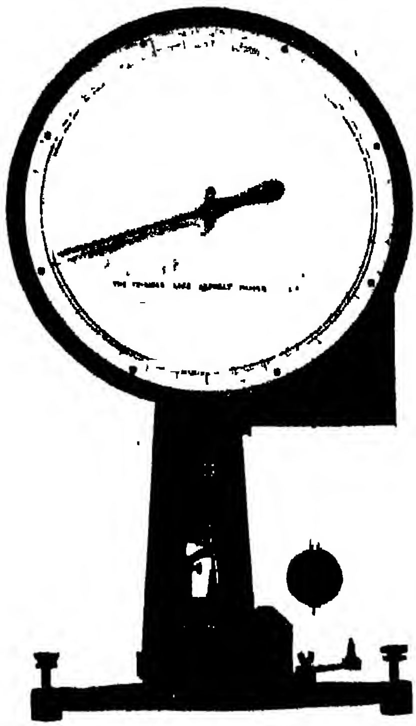


FIG. 47A.—Penetrometer.

A small piece is cut off the sample and weighed in air and in water:

$$\frac{\text{weight in air}}{\text{loss of weight in water}} = \text{specific gravity.}$$

A second sample is taken weighing exactly 10 grms. This should be broken up into fragments and placed on a filter paper in a funnel which discharges into a flat-bottomed assay flask. A quantity of carbon disulphide is poured gradually on to the sample, and the bitumen is thereby solved out of the mixture. This process takes several hours. The solution of bitumen in the assay flask (after standing, so that all the sediment has settled) is then carefully decanted.

Some fresh carbon disulphide is poured on to the sediment left in the flask, the contents poured on to the filter and the flask thoroughly cleaned free from all sediment, which is added to the mineral sediment already mentioned, and this is washed clean with the carbon disulphide

The solution of bitumen is poured into a dish and ignited, and the remainder is added to the mineral matter.

The mineral matter, after the carbon disulphide has completely evaporated, is removed from the filter paper, scraping it in order to remove the fine material, but being careful not to remove the paper itself The paper is also ignited and the ash added to the mineral matter. The total weight of the mineral matter and fine ash is then taken, and the difference between the weight so obtained and 10 grms. gives the weight of bitumen in the sample.

The whole of this mineral matter is then placed on a 200-mesh sieve, and as much of the finer material is caked together, this is carefully broken up between the fingers and pressed through the sieve. When it is evident that there is no more that will pass this mesh, it is removed from the container underneath and weighed on the chemical balance.

Similarly the 100, 80, 50, 40, 30, 20, and 10 meshes are dealt with and the results tabulated.

	Weight.	Per cent.
Bitumen	..	..
Passing 200 mesh	..	..
,, 100 ,,	..	..
,, 80 ,,	..	..
,, 50 ,,	..	..
,, 40 ,,	..	..
,, 30 ,,	..	..
,, 20 ,,	..	..
,, 10 ,,	..	..
on 10 ,,	..	..
	10 grms.	100 per cent.

It is interesting to keep a record of the density or voids in a structure. In order to obtain the density and voids, it is necessary to know the specific gravities of the composite minerals used in the mixture.

Sand has usually a specific gravity of 2·65, but this should be tested. If cement is used as the filler the specific gravity is about 3.

The bitumen that is used in the mixture will vary, but it has usually

a specific gravity of 1·06. A bitumen such as that from Trinidad Lake in the *epuré* form has a specific gravity of 1·40, but it is used only in a mixture when it has been fluxed with a petroleum flux which may have a specific gravity of about 0 95, and the amount of flux used will lower the specific gravity to about 1 26. Even with this fluxed bitumen there is an amount of mineral matter which, if removed, would bring the specific gravity down to that mentioned, viz. 1·06.

Assume that a mixture was made up as follows :—

Per cent.		Sp. gr.		Volume.		Per cent.
20	Granite dust	2·82	=	7·1	=	16·14
55	Sand	2·65	=	20·75	=	47·15
8	Cement	3·00	=	2·66	=	6·04
17	Trinidad bitumen *epuré*	1·26	=	13 50	=	30·67
100				44·01		100·00

The average density should therefore be :—

16·14	at	2·82	=	·45
47·15	„	2·65	=	1·25
6·04	„	3·00	=	·18
30·67	„	1·26	=	·39
				2·27

The specific gravity of the mixture, as taken from the test of the sample of pavement, was shown to be 2·23 Therefore the percentage of voids was just about 4 per cent.

If the specific gravity is required of any material composed of fine material, it is perhaps better that it should be determined by an analyst, as it is difficult to weigh the dust in water. It is usually done in a spirit such as alcohol or petrol, and the expert analyst is more accustomed to perform this test than one who has to make the test at very infrequent intervals.

Similarly, in regard to the chemical tests of bitumen, the tests for malthenes, carbenes, etc., should be carried out by an analyst. The description of the method is indicated briefly.

Loss on Heating.—A glass dish 1½ inches diameter and 2 inches deep is filled with 20 grms. of the bitumen to be tested. The receptacle and its contents are then placed in an oven, the temperature of the oven being brought to 325° F. and kept at that figure for seven hours. The difference between the original weight and the weight at the end of seven hours is the loss during that time.

A different sample is taken if the test is to be at a temperature of 400° F.

The Amount of Bitumen soluble in Carbon Disulphide.—One grm. of the bitumen (refined) is placed in a flask and covered with a plentiful supply of carbon disulphide (100 c.c.): it is allowed to stand overnight. The solution is then decanted on to a filter (already weighed), the mineral matter that has subsided being left with as little disturbance as possible in the flask. This is further treated with carbon disulphide and again allowed to subside. The process is repeated, but the whole of the subsided matter is now poured on to the filter. The filter is washed with carbon disulphide until the mineral matter is perfectly clean, then the carbon disulphide is allowed to evaporate completely, and when thoroughly dry the filtrate is weighed and the allowance made for the weight of the filter.

The disulphide which has passed the filter is allowed to stand for twenty-four hours and then decanted into a crucible. If there is any matter which has further subsided, this is washed and added to the filtered material.

The decanted solution is burned, and the remainder is mineral matter which is also weighed. The total of all these weights of mineral matter is deducted from the original weight of 1 grm., and the result is the amount of bitumen soluble in carbon disulphide.

Bitumen soluble in Naphtha.—Naphtha 88° and 62° Beaumé is used. The bitumen must be powdered, or if soft cut into a finely divided state.

Practically the same method is employed in making the test as is the case in the solving out with carbon disulphide.

The bitumen soluble in naphtha is technically called "malthenes."

The 88° naphtha solution is made up to 100 c.c., and an equal volume of naphtha 88° is placed in a second flask. They are both treated with 30 c.c. of H_2SO_4, specific gravity 1·84. The naphtha solution and the naphtha are washed with water and with a 5 per cent. carbonate of soda solution and a subsequent washing with water. They are then poured into two dishes. In the plain naphtha is dissolved 50 grms. of a stable petroleum residuum. The naphtha is evaporated until the plain naphtha has its residue at its original weight. It is then assumed that the naphtha is entirely evaporated from each.

The difference gives the amount of the solution which is solved by sulphuric acid.

E.g. if the bitumen is soluble in 88° naphtha to the extent of 36 per cent., and the amount of bitumen soluble in $CS_2 = 56·5$,

then $\frac{36 \times 100}{56·5} = 63·7$ per cent. soluble of the total bitumen.

If 60 per cent. is the amount of the soluble bitumen removed by sulphuric acid, then the saturated hydrocarbons in per cent. of total bitumen

$$=63{\cdot}7-\frac{63{\cdot}7\times 60}{100}=25{\cdot}48 \text{ per cent.}$$

bitumen soluble in carbon tetrachloride.

The process is precisely the same as for the bitumen soluble in carbon disulphide.

More elaborated details of the analyses will be found in Mr Clifford Richardson's *Modern Asphalt Pavements*, and Mr Prevost Hubbard's *Laboratory Manual of Bituminous Materials.*

CEMENT CONCRETE ROADS.

One of the first questions the road engineer asks himself when confronted by the difficulties experienced in finding a suitable road structure to satisfy the requirements of present-day traffic is—Why will not a Portland cement concrete surface be the solution of my difficulties? It has been used in many towns as a pavement for footpaths, it has also been used in streets with very light traffic, it is used as a foundation for wood paving but is kept at a distance of 4 inches at least from the actual wearing surface; it is similarly used for the foundation for natural rock asphalt, and is within 2 inches from the surface. But in scarcely any case under heavy traffic conditions has a cement concrete been used as the surfacing material.

Concrete Roads in U.S.A.—Recently this form of surfacing has been brought into prominence by the work that has been done in the U.S.A. Photographs of roads that have been constructed with this material are given, but in each case that the writer has seen the road is absolutely free from traffic. A more convincing view of a road so surfaced would have been a photograph showing the road with a large number of vehicles travelling in the ordinary way of business over the surface; one is therefore inclined to be sceptical of its value, and when one of the engineer writers makes the statement that the roads so constructed are not very successful, such testimony is more apt to be accepted as genuine than that of the many who voice its success, especially so if the anticipation of failure is the outcome of a close examination of the probable effects of traffic on such a material. The success of a pavement largely depends on the point of view; *e.g.* if an inferior road structure has been expensive to maintain and another less inferior structure is substituted, then the latter, being less costly to maintain, is obviously a success in comparison with the inferior structure. But both of these pavements

may be outclassed by structures which withstand this and a still greater intensity of traffic at much less cost, hence the success is merely based on figures which are far from ideal.

Difficulty to be overcome.—Cement concrete laid *in situ* has one particular characteristic which makes it a difficulty which is practically insuperable in a road-surface structure: it is in the length of time the concrete takes to "set." It is not unreasonable to say that cement concrete should not be used under three months after it is laid.

Cement concrete improperly set will wear almost as badly and as rapidly as water-bound macadam; the wear would be wholly due to the effects of surface friction

Non-resilient Structure.—Cement concrete is a non-resilient structure, and therefore as soon as the traffic comes upon it, it must commence to wear. The wear may take the form of reducing the size of the particles forming the concrete while remaining in the pavement, or the particles may be removed bodily from the structure; and in those cases which have come before the notice of the writer, the latter seems to be the result rather than the former, hence the wear is more rapid than would be the case with asphalt or a bituminous concrete.

Asphalt pavements being composed of similar material, except that bitumen takes the place of cement as the binding agent, are resilient structures, and traffic resistance is less destructive to this class of pavement on that account. It is exhausted by compression and wear, but the part that is worn is returned to the pavement, because the bitumen in the structure is capable of reabsorbing this finely divided material. This will go on for some considerable time, until the bitumen becomes incapable of receiving the worn material, and it becomes a dust which is eventually removed or blown away, thus exposing another layer which is capable of repeating the action Hence the wear of an asphalt pavement is very slow and much less costly than a cement concrete pavement.

The writer has had examples of asphalt pavements which have taken nearly twenty years to wear down to about ¾ and ½ inch thick (from 2 inches and 1½ inches as originally laid) before distinct disintegration takes place. Cement concrete has neither ductile nor any adhesive qualities about its structure; its wear must under severe traffic conditions presumably be heavy in comparison, and there are almost invariably weak areas which will give way more rapidly still, due to the human element in the mixing and laying.

Repair of Concrete.—These areas will require repair, and it is well known how difficult it is to repair an *in situ* concrete pavement and at the same time make a satisfactory job of it, especially so when it re-

quires such a long time before the material is properly "set." Repairs on a road with heavy traffic should be capable of repair on one day, and on the next should be open to traffic. This is practically impossible in a concrete road. Hence the concrete, when it has to be repaired, becomes a nuisance. The writer had to abandon, in the case of an area laid with concrete, the use of cement concrete, and eventually had to fill the hollows up with a bituminous concrete which was quite satisfactory so far as the traffic was concerned, but was an eyesore in the concrete surface.

For lightly trafficked roads cement concrete might be used with advantage, because a sufficient length of time could be given for the concrete to set, and even in moderately trafficked roads it might be used and prove cheaper than ordinary water-bound macadam; but in this case the concrete ought to be watched carefully, and when it is worn to a certain thickness it should be coated over with a bituminous wearing surface.

Wearing Surface at End of Life of Concrete.—Cement concrete—when bitumen is unavailable in sufficient quantity—may be used as a base for a bituminous wearing surface coat. But where bitumen can be obtained at reasonable rates, it is far preferable to use the bituminous concrete as a base for the coat, because the coat has an affinity with the base and would adhere more satisfactorily to such a structure than to a cement concrete base. It has been suggested that the concrete might be used as a base for a bituminous film $\frac{1}{8}$ to $\frac{3}{16}$ inch thick, but it is extremely difficult to lay such a substance on the concrete, and after a time it can easily be peeled off.

In a case of repaving a wood-paved area on the old concrete, the blocks were not available for the repavement, and in order that the heavy and continuous traffic should not be deprived of the road, it was allowed over the old concrete surface. Wear was soon in evidence, and it was fortunate that the difficulty of the supply of the blocks was overcome, otherwise the road would have had to be dealt with in some other manner.

The cement concrete road must not be put on one side as an impossibility, by any means. In the U.S.A. many miles of roads have been laid with satisfactory results. The concrete is laid in 25-feet sections; each section is divided from its neighbour by an expansion joint $\frac{3}{8}$ inch wide, which is filled with asphalt, thus allowing for expansion and contraction of the concrete. The concrete consists of 3 parts of stone, $1\frac{1}{2}$ parts of sand to 1 part of cement. Concrete mixers are used, and the concrete deposited mechanically; a special machine is used for forming and finishing off the surface. The concrete is covered with

earth, which is kept in a moist state for from four to six weeks. The cost of the concrete roads in U.S.A. runs out at about £3000 per mile, the width being 18 feet.

During the war concrete roads have been made by the War Office, Admiralty, etc. One road is spoken of highly by the superintendent engineer, but the photograph accompanying it does not indicate that it is heavily trafficked.

At Southampton a road was laid at the docks. The substructure was good, and the concrete was laid above the old macadam that formed the road previously. The concrete was laid 6 inches thick, the lower 4 inches being in the proportion of 6 to 1, the upper 2 inches being 3 to 1. Sea gravel passing a ⅜-inch mesh was used. The lower concrete was reinforced by the British Reinforcement Concrete Company's material. A length of 12 to 15 feet was laid each day. Each length was covered over with tarpaulins, the process being to omit a length and fill up the intervening length a week afterwards. No expansion joint was provided. The work occupied five weeks, and the traffic was turned on to it five weeks later. The surface was coated later with hot tar and dusted with coarse sand. This was in November 1917, and it therefore is not yet proved as to its capacity.

Concrete Brick Pavement.—What seems to be a better policy from many points of view is to make concrete bricks and pave the road as is done with setts, but with a fine joint, as is the case in wood-block paving. The repair difficulty is removed, the setting of the concrete is not a hindrance to the use of the road, and the bricks are more likely to be uniform in structure than an *in situ* pavement, however carefully it may be laid.

The crushed clinker from the plant mentioned on page 195 was used in the manufacture of paving slabs in the proportion of 3 of crushed clinker to 1 of Portland cement. The slabs were well matured even before using them in footpaths: they were 2 feet × 2 feet and 3 feet × 2 feet. The smaller-sized slabs were used in an experimental area of road. Considerable care was exercised in laying them to secure a solid base, but after a few days' traffic upon them they cracked and eventually had to be removed; it was evident that the care in laying them had not been sufficient to prevent hollows from being formed under the slabs.

The plant was also erected for the purpose of making bricks, and a few hundred thousand were made with the crushed clinker and Portland cement in the proportion of 15 to 1 and 9 to 1. The bricks were subsequently tested for crushing, with the following results, in respect of those made of the 15 to 1 composition:—

				Tons per sq. ft.
Age	5 weeks	5 days	.	216·5
,,	7 ,,	5 ,,	. .	206·5
,,	9 ,,	5 ,,	. . .	212·7
,,	11 ,,	5 ,,	. .	249·3
,,	13 ,,	5 ,,	. .	281·9
,,	15 ,,	5 ,,	. . .	274·7

These tests show that at a stage of about six weeks they can resist a severe crushing strain, but that for a month after the resistance to crushing is backward, then it increases rapidly up to the fourteenth week, when it remains more or less stationary.

The writer has seen a similar forward, backward, and subsequently forward movement in other tests; they indicate that the concrete does not reach its full maturity before the thirteenth week. Whatever results may have been secured in those areas where the traffic was only kept off the concrete for six weeks, it is evident that even better results would be attained by the longer period.

The bricks were subsequently used in building work, but so dense were they that there was a certain amount of dissatisfaction to the bricklayers not only on account of their weight, but in the difficulty experienced in cutting them for closers, etc.

Cost of Bricks.—The cost (pre-war) of these bricks was about 21s. per 1000, and as about 46 would be used in covering a superficial yard, the cost of the bricks alone would amount to about 1s. per superficial yard, to which would have to be added the labour in laying a suitable foundation.

No tests have yet been made with these bricks on a road, but there is no doubt that experimental sections will be laid down to test their value; because, even if the cost was increased, by reason of the appreciation in all values, to 2s. per superficial yard, there would be an advantage to local authorities, as it would not only provide a means of disposing of the clinker refuse, but it would also give a very good surface, far cheaper than macadam and more satisfactory as regards maintenance. Whether they would serve for heavy traffic is a matter that must be proved.

CHAPTER X.

ROLLERS AND ROLLING.

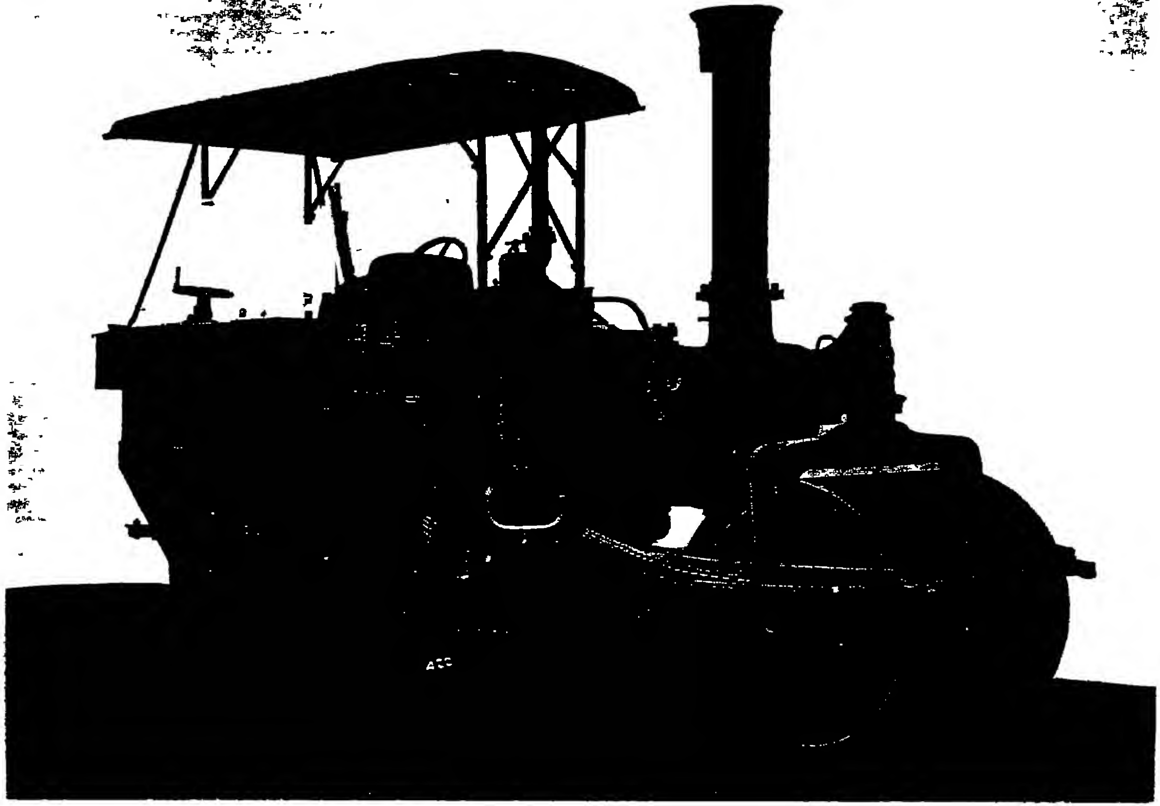
In every process of macadam and asphalt construction some method of consolidation is necessary before it can be claimed that a road has a good surface.

Rollers.—In the past, the macadam was evenly spread over the surface of the road, the mud that had been previously swept from the old road being thrown over the loose stone as a binder, and in order to consolidate the two, various obstructions were so placed that the traffic took a winding course, and the stone thus settled into its position. Whenever any area became fairly consolidated, the obstructions were moved to a new place, and eventually by these crude methods the whole surface became more or less even. It was slow, unsatisfactory, and most inconvenient to traffic, and, as a result, the horse-roller came into existence; similarly, this had to give place to the steam-driven roller, which proved capable of securing the even surface quickly, effectively, and economically. The rollers were at first about 6 or 8 tons, then heavier rollers up to 15 tons were constructed, and it was only due to the damage caused to the gas and water mains, and the difficulty of getting them safely over bridges and culverts, that the weight of the average steam-roller was brought down to 10 tons, and it is this type of roller that is generally satisfactory in the work it is expected to perform, *i.e.* in consolidating the ordinary water-bound macadam road.

For tar macadam, however, it is found that the 6- or 8-ton roller is more satisfactory, the heavier rollers being found to squeeze and push the material out of place, and so making it extremely difficult to obtain a good and even surface.

It has already been pointed out that the steam-roller that is in general use for water-bound macadam crushes the stone or so abrades it that a powder is formed, and the binding between the stone that is required is thus obtained. In any other form of construction the

[*To face p* 219.



roller is not required to crush the stone and form a binding material, the binding agent being supplied in the form of tar, bitumen, or other material. Consequently, the 10-ton or 12-ton roller is too heavy for such methods of construction, because if the stone is broken or crushed, surfaces are exposed which are not coated with the binding agent. In cold mixtures, *i.e.* tarred macadam, chippings, etc., the stone would not as a general rule be broken, but individual pieces would more probably slide over each other, and in this process be deprived of the binding agent. On the other hand, if the stone was not crushed or did not slide under the roller, there would be considerable compression; consequently, there would be a decrease in the air spaces or voids, and the construction is brought nearer to the period when the ravelling of the material commences, *i.e.* when the total compression is reached. In other words, the heavier the roller and the more the surface is rolled, the shorter will be the life of the road.

It must not be forgotten that it is useless to consider the weight of the roller without taking into consideration the width and diameter of the wheels.

The proportion of weight on the front and back wheels varies from 1 to 3–1 to 2, *i.e.* a 12-ton roller may have 3 tons on the front wheels and 9 tons on the back; in other cases it is 4 tons on the front wheels and 8 tons on the back. The front wheels or rolls are usually 4 feet wide, while the back wheels are from 15 to 16 inches wide (total, 2 feet 6 inches to 2 feet 8 inches); thus the weight on the front rolls is from $\frac{3}{4}$ to 1 ton per foot of width, and on the back from about 3 to $3\frac{1}{2}$ tons per foot of width. Similarly, the 10-ton roller gives about the same proportion, for the reason that the rolls are slightly reduced in width. The 6-ton roller is about $\frac{3}{4}$ ton per foot on the front rolls, and $1\frac{2}{3}$ to 2 tons on the back rolls (fig. 47B).

The front wheels have a lighter weight per foot in order to facilitate steering, but the increased weight on the back wheels is due in large degree to the fact that the boiler is usually of the horizontal type. In America, rollers have been made with the front and back wheels of the same diameter and width, and a vertical boiler has been placed between the two wheels, thus enabling the weight to be more easily and equably distributed, so that a 10-ton roller gives a pressure of about $\frac{3}{4}$ ton per foot of width of roll on the front and $1\frac{1}{4}$ tons on the back rolls. This type of roller is found to give the correct and requisite compression to asphaltic mixtures. The tandem roller is undoubtedly the best type for the processes, which include a liquid or semi-liquid as the binding agent.

In order that a road may resist satisfactorily any extraneous force

which may come on to its surface, the amount of rolling that is necessary to give an even and regular surface and to ensure the particles composing the mass being in sufficient contact only should be given. By this method the material is allowed to exercise its functions, *i.e.* the resiliency of the composition and the ductility of the binding agent. If, on the other hand, it is so rolled until the full compression is taken up, the composition becomes non-resilient, the binding agent is not allowed an opportunity to exercise its ductile qualities, and the material as a whole is not probably as good as a cement concrete

In asphalt pavements it will have been noticed that the powder is laid in a hot condition; it is compressed with hot irons; the pressure that is exerted by these irons is not more than ¼ to ½ ton per square foot, and this pressure is all that is necessary for the consolidation of this material.

In order to prove conclusively that the heavy pressure of a steam-roller would give full compression, samples of sand and chippings were heated and dried and each filled into a box, the volume of which was exactly 1 cubic foot. The weight of the sand when compressed dry was 101·75 lbs., and the air spaces found to be 38·5 per cent. The ⅜-inch granite chippings when compressed dry were 102·25 lbs., and the voids 42 per cent.

The chippings were removed from the box and then gradually poured into the box together with the sand, in order that the latter should fill the air spaces of the former. This resulted in the cubic-foot box containing 94 lbs. of chippings and 48 lbs. of sand, *i.e.* the total weight in the box was 142 lbs., and the voids were now reduced to 18 per cent. 15½ lbs. of bitumen will take up a space of 18 per cent. of a cubic foot. The 94 lbs. of chippings, 48 lbs of sand, and 15½ lbs. of bitumen were all thoroughly mixed together, and in their hot condition the mixture, by means of forcible tamping—*i.e.* a 26-lb. rammer raised about 12 inches high and dropped on to the composition as it was placed in the box—completely filled the box. The pressure exerted would not exceed 1 ton per square foot.

It is evident, therefore, that in any hot process or with the binding agent in a somewhat liquid condition, the pressure brought on to the surface should not exceed about ¾ ton per square foot, and the binding agent should be just on the point of setting.

It has been suggested that rolling is the cause of the waviness of the surface of the bituminous mixtures. The writer does not incline to this theory. There are many tar macadams which are not wavy and which have been rolled; similarly asphalt pavements are "wavy," and they are not rolled but "tamped." The waviness is more likely

to be caused by the traffic and the atmospheric heat, which is severe on the surface and lessens with the depth of the material; the top layer, being more susceptible to movement, is pushed forward by the traffic.

But the action of the roller in pressing the material forward or backward as the roller moves in these directions is not wholly desirable. It is preferable that when the material is placed in position, it should

FIG. 48.—Crompton's three-axle roller.

not be disturbed more than is absolutely necessary to fix it there. This would probably be more efficiently performed by a vertical blow, which type of pressure would tend to keep the stone vertical, whereas the rolling motion tends to bring the flat sides of the stone to the surface.

But a tamping machine which would cover large areas quickly has not yet become a commercial possibility, and it is open to question whether the class of rolling suggested above will not surmount the difficulty in a satisfactory manner.

It would seem a desirable condition that in a road surface constructed with a theoretically voidless composition, the composition should be so rolled that there will be at least 10 per cent. voids, and if the material

will not break away, as much as 15 per cent. when it is newly laid. There are, however, some compositions, such as the tar macadams and chippings made of the same sized stone, when total compression is obtained with 30 per cent. voids in the mass In this material the voids should therefore be about 45 per cent. when it is newly laid. This line of argument fails when applied to a material that sets hard and is not likely to be broken by succeeding traffic.

From the above considerations there is evidently room for a new design of roller to meet these requirements; that is to say, one that will weigh about 6 tons and be not more than 1¼ ton per lineal foot width of roller. Both petrol- and steam-driven rollers are applicable, but if the steam-driven vehicle can conform to the weight standard, it will probably prove more satisfactory for road work owing to its flexibility.

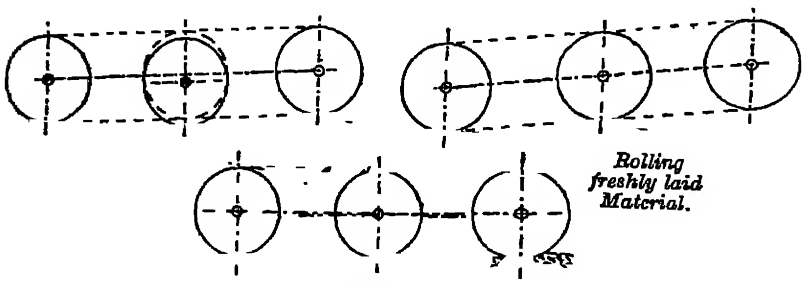


FIG. 49.

Three-Axle Roller.—Colonel Crompton, C.B , has designed and constructed what he terms a three-axle roller. He says that, in order to obtain a perfect levelling action of the rolled surface, the weight taken by the three rollers must constantly vary so that it can exert maximum pressure on the high places and a minimum pressure on the low ones. At the same time there must never be less than sufficient weight on the centre driving roller to enable it to have the required driving adhesion.

In his roller these conditions are met by mounting the centre roller only on springs in such a way that it can fall below but cannot rise above a fixed point relative to the front and rear rollers The action of the rollers is then as shown in the diagrams. In fig. 49 the front roller is seen on the summit of a wave or high place, the centre roller having sunk below its normal position, which is indicated by the dotted lines; when the centre roller passes over the same summit as shown, it takes practically the whole weight of the roller, which tends to reduce its height. If the centre roller was not provided with springs as described,

the rear roller would tend to leave a depression when in the position shown in this figure. Fig. 49 shows the action of the machine when rolling freshly laid material.

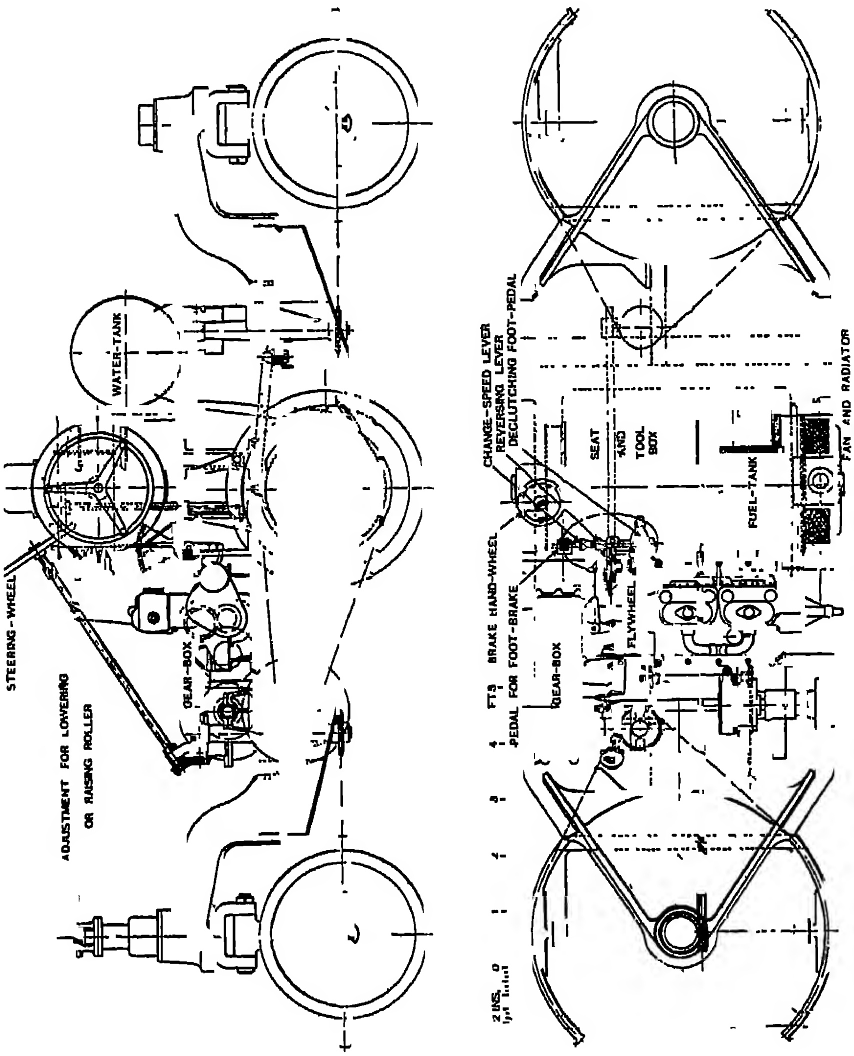


Fig. 50.

It will be seen that the rolling surfaces of the rollers are not quite in the same plane, but that the centre one is then slightly below the level of the other two. This gives a very light pressure during the first time of rolling, which gradually increases each time the roller comes back

on to the cooler and harder material already rolled. This is due to the fact that as the road surface becomes less yielding the weight becomes more concentrated on the central roller, giving the much desired effect, just as if a light roller was first employed followed by a heavier one, but the change from light to heavy being more gradual. The difference in the level of the rollers is adjustable by arrangements on the front steering head, and extends over a range so sufficient that, if necessary, the rear roller can be permanently raised off the ground, concentrating 90 per cent of the total weight on the centre roller. The front roller always has sufficient excess of weight to give steering effect. The wheel bases are not equal. This is purposely arranged as a further precaution against the possibility of producing recurring waves.

The diameter of the central roller is 3 feet 6 inches, and that of the two end rollers 3 feet. In a later design the central roller is 4 feet. The width of the rollers over all is 4 feet. The long-wheel base is 8 feet, and the short-wheel base 6 feet 6 inches.

The distribution of the weights can be varied between the limits given in the table below, with a corresponding rolling-pressure variation of from 160 lbs. up to 500 lbs. per inch width of roller.

Front Axle.		Centre Axle		Rear Axle		Total.		
T.	C.	T.	C.	T.	C.	T.	C.	
0	17	8	10	.				
3	8	3	8	2	11	9	7	Without water ballast
0	17	10	13	.	.			
4	2¼	4	2¼	3	5½	11	10	With water ballast

CHAPTER XI.

PAVING.

Granite Sett Paving.—The various kinds of paving for very heavy traffic, such as are found about docks and other commercial centres, are of the granite sett type. Granite setts are of various sizes, about 5 or 6 inches deep, 3 to 3½ inches wide, and from 7 to 9 inches long, properly square and dressed. It is usual to lay them on a 6-inch concrete foundation. There is a bed of sand about 1½ to 2 inches deep, in which the setts are bedded on parallel courses, the joints being about ⅜ to ½ inch wide, and these are filled up with chippings, into which is poured a pitch and anthracene oil mixture of a standard type already described. The setts are obtained from various quarries, *e.g.* Penmaenmawr, Aberdeen, Mount Sorrel, Enderby, Cornwall, Norway, Belgium, etc.

In many cases the setts are 3-inch or 4-inch cubes, laid as described in the case of the larger material.

This form of paving has its disadvantages: the edges under traffic conditions are soon broken, and the surface becomes corrugated; it is noisy, and not particularly clean on account of the mud collecting in the joints and the difficulty of cleaning it out.

Kleinpflaster or Durax.—Another form of paving is known as Kleinpflaster in Germany, where it is extensively used. In the provinces of Rhine, Westphalia, and Hanover hundreds of miles have been laid with economical results. A considerable area of the Thames embankment at Chelsea and also other districts have been paved with this material, which is known as Durax in this country. The stones are made in the form of truncated pyramids, and are not of the same size but vary in depth according to the density of the traffic, the surface dimensions varying from 3 to 1½ inches. The paving is laid in sand, and the joints are filled with sand or a consistency of pitch or cement. No foundation is necessary except what may be provided in the existing road, or what would have been provided in the ordinary macadam road. The paving

is not laid in parallel lines, but in quarter circles similar to mosaic paving. It is claimed that this method prevents the edges of the paving from being broken, and the corrugated appearance that is found in ordinary sett paving is not in evidence. This form of pavement should prove to be better than sett paving; it will be much cheaper on account of the more economical use of the stone, the sizes being much smaller and therefore giving a greater surface area per ton of material used. It will wear more satisfactorily, but it is not a noiseless pavement, although it is claimed to be less noisy than sett paving.

Grit-Stone Paving.—In Lancashire and Yorkshire sett paving is common, but not of the granite type. The stone is a grit stone which is quarried locally; it is usually about 6 to 8 inches wide, the length 6 to 9 inches, and the depth about 6 inches. The paving is treated exactly in the same way as the granite sett paving.

Every few years, depending on the traffic, both the granite and gritt sett pavings are taken up, redressed and relaid, and they then give a face equal to new paving.

Grouting of Sett Paving.—It will probably be a feature in the future to increase the life of the sett paving by adopting a more satisfactory filler for the joints than the consistency of soft pitch, which soon deteriorates and wears away to a depth of about 1½ inches below the surface. Probably mastic asphalt could be adopted. By increasing the size of the joints between the setts, this substance could be placed in the space so afforded, and as it would not so easily break up as pitch, would prevent the edges of the setts from being worn, and incidentally also give a good foothold for horse traffic and a more even and therefore less noisy surface.

There would be no reason to go lower than 2 inches, because the pitch below that depth is in practically an air-tight chamber, and as the setts are not capable of being moved from the position in which they were originally placed, the pitch retains its elasticity for many years.

The writer tried a few yards of paving on these lines with very satisfactory results; the stones had to be laid with greater care, and considerable expense was thereby involved.

Brick Pavements.—Brick pavements are common in Holland and in America. The eastern States have laid considerable areas.

The bricks used are hard and tough, and must resist the action of frost, acids, and water. They must not absorb more than $\frac{1}{500}$ of their weight in water during forty-eight hours. They must not polish under wear, be compact and close-grained, free from air holes and pebbles, and give a clear ringing sound when struck; they must not scale or chip when struck on the edges.

They are burned to a temperature of 1500° to 1800° F., depending on the clay, and the heat is gradually lessened until the kiln is cold. If cooled too suddenly they will be brittle. The difficulty is to obtain the bricks of even texture and quality. The analysis should be :—

Silica	60 to 75 per cent.
Alumina	22 ,, 23 ,,
Sesquioxide of iron . .	3 ,, 9 ,,
Lime	not more than 1 ,,

They are laid similarly to setts, and jointed with pitch and tar grout

The paving has not proved suitable for heavy traffic

WOOD PAVING.

Hard-Wood Paving.—The next process of importance is wood paving, laid on a concrete foundation, which must have a perfectly smooth and even surface. The more satisfactory the foundation the better will be the results. The timber that is used is either "hard" or "soft." Hard woods are oak, blackbutt, Jarrah, and Karri. The most popular of the hard woods is Jarrah. It is grown in Australia, and the trees from which the timber is cut are of considerable diameter. The quality is apparently perfect; the rings are exceedingly close; there are no knots; there is a density and hardness which, from a superficial view, would make an excellent surface, but it is in practice found to be too hard and unyielding. One persistent fault is that it shrinks, the edges wear, and the surface in time has a corrugated appearance, with fairly large joints, and it thus becomes noisy and not particularly clean.

The results that have been obtained are more or less satisfactory, according to the degree of satisfaction required. The writer has seen the paving in seaside towns wearing without that contraction which has been so evident in London and elsewhere, probably because the sea air gives to the timber the amount of moisture that it requires to prevent contraction, or it is in some other degree suited to its surroundings.

Dowelled Blocks.—The writer laid an area with dowelled blocks, but these developed a crack 1½ inches wide in the middle of the paving, and the only means of preventing further damage was continual watering of its surface during the summer. This trial was not a success, and eventually it was removed; soft-wood paving would have lasted more than twice the life of this pavement and been cheaper in first cost.

In order to overcome this difficulty of contraction, the Acme Wood Paving Company has adopted a process of cutting up the material

into small pieces and making them into a block again by a kind of dowel running its entire length on either side. The cost of laying these blocks varies with the depth of block required They are 3-inch, 4-inch, or 5-inch.

Soft-Wood Paving consists in the use of blocks which are cut from 8-inch or 9-inch deals, and are usually 5 inches deep and 3 inches wide. The timber generally used comes from Sweden, and is known as red pine and yellow deals. Spruce and timber from Archangel is also used.

Scandinavian and Russian Woods.—The timber that comes from the ports of Gefle or Soderham, in Sweden, is of the finest quality for wood-paving purposes; it is close-grained, hard, and very even in quality. The timbers from the northern ports of Sweden are softer in texture, close-grained and even, but have not the same wearing capacity. The deals from the southern ports of Sweden are of a coarser character, the rings are wider, and the amount of sap or sapwood is considerable. In these deals the sapwood is comparatively soft and the heartwood is very hard, so that with concentrated traffic, such as is common on the main London thoroughfares, the wear takes place in small depressions due to this soft fibre wearing more rapidly than the harder texture of the block.

Spruce deals may be found to be good, but the general quality is soft, even more so than the timber from the northern ports of Sweden. It does not wear so well, and its life is therefore shorter. *Archangel timber*, if carefully examined, is of very good quality, but it is only the ends of deals that are available, as the full deals are sold for joinery work. Most of the timber from *Riga or Finland* is too soft for paving purposes. But in the use of timber for wood-paving, consideration must be given to the traffic which uses the road It may be possible to find a timber which might prove to be as effective from a wearing point of view as the best quality. It is a matter of selection, which requires considerable experience and can hardly be set down on paper.

Archangel *larch* is neither a hard nor a soft timber. The writer has tried it in several roads for short experimental purposes, and so far has every reason to be satisfied with the results. It is a timber which is so dense that it will absorb but a very small quantity of creosote.

Rings in Timber.—The reason why red pine in different parts of Sweden varies in character is due to the richness or the poverty of the soil and to the atmosphere. It is quite conceivable that the growth of a tree in a swampy district or in one where the soil is rich will be considerable; in those parts where the soil is poor the growth of the timber or fibre will be of a less strong character,

and in those areas where very cold weather prevails for a considerable proportion of the year, the growing period is short in comparison, and hence the rings are closer together and forms timber more dense and even in character.

The more rings visible in the deal, the older will be the tree from which the deal has been cut.

Sap or Sapwood.—It does not necessarily follow that sapwood, which is usually condemned in timber for building purposes, will be unsatisfactory for paving purposes; but there are points which should be observed, viz. that the sapwood in a deal with a very hard heartwood will prove unsatisfactory, because of this uneven characteristic; whereas, if the sapwood and heartwood was of an even character, both would probably wear equally well when creosoted. It is therefore a matter for critical examination, and the engineer has to consider whether a timber which might be useless for other purposes would not be adaptable for road surfaces.

Pitch-Pine has been successfully used as a wood-paving material. Creosoting would in this case be of little value, as the timber is full of resin which would prevent the creosote from penetrating.

Creosoting.—All soft woods are creosoted at the rate of 10 lbs. of creosote to the cubic foot of timber. The creosote should contain 8 per cent. of tar acids. Before creosoting, the timber should be properly seasoned and not newly delivered, as frequently the timber contains moisture, and if this has not been eliminated the creosote will not take its place, but only penetrate the block in parts. Then there are defects in timber which can only be detected by one who has expert knowledge, and can tell the difference between "dead" and "live" timber.

Creosote is used in order to lengthen the life of the timber. It is quite possible that in some roads, where the traffic is very heavy and the life of the paving very short, creosoting has little, if any value, except to the sapwood portion of the block, because the wear of the block is more rapid than the decay of the timber. The writer has known ordinary deals cut in blocks, laid in a roadway, which after a period of twelve years have shown no sign of decay.

In some districts uncreosoted timber has been laid in the main thoroughfares for many years without apparent disadvantage, but there is a sanitary advantage in the fact that the creosote sterilises the urine and prevents it penetrating into the fibre of the block.

Method of Laying Blocks.—The blocks are laid on a perfectly smooth face of concrete. The concrete is usually about 6 inches thick (6 to 1),

and a surface of concrete made with 3 of sand to 1 of cement is floated over the face of the concrete to the surface, which is to be exactly the depth of the block below the finished surface. The concrete should be exposed to the air for a fortnight, and the surface floating for at least a week, so that when the time arrives for the laying of the blocks the concrete shall be properly set and hard. The blocks may be dipped in a hot composition of slowly distilled tar in the form of pitch, generally known as "soft," *i.e.* a penetration of about 70° and 80° F. on the standard penetrometer, and immediately laid close-jointed. Afterwards the joints are filled up within 1 inch or 1½ inches from the surface with the mixture of pitch and the remaining portion is filled with cement and sand (2 to 1). It must be carefully examined to see that the joints are properly filled with pitch, otherwise the water will penetrate between the blocks and get under them, and probably lift them, so that they will have to be relaid.

The blocks should be laid in hot or moderately hot weather, that is, when the blocks are at the least size by reason of their contraction; but it is not imperative that this should be the case. For soft-wood paving the space at the kerbs should be 1½ inches, and filled up with clay, so as to allow of the timber expanding without doing damage to either kerbs or flags forming the footway.

Advantages of Soft-Wood Paving.—The advantage of this class of paving is that it is silent and is not slippery; also, if a block should show weakness, the surrounding blocks wear down to that of the weaker block, so that the depression is not, as a rule, very sudden, and the surface even towards the end of its life is of a smooth and comparatively even character.

Life of Soft-Wood Paving.[1]—The life of the creosoted block is difficult to determine. The writer has taken up a pavement that has been down for seventeen years, but as there is always a fair proportion of the area of the streets that receive only a small proportion of the traffic, those areas will give up a quantity of blocks that show little wear. The whole of the material is taken to the depôt and the timber sorted into various sizes—3 inches, 3½ inches, 4 inches, 4½ inches, and 5 inches. The blocks are cleaned free from tar, cement, etc., and the edges squared, and this timber is laid again in the streets In one case there was a section of a main thoroughfare laid with blocks that had been previously used in a road during a period of fifteen years; after being down about four years these were again cleaned, and have been placed in other roads wherever repairs have been necessary. Thus it is quite within reason to say that the blocks will last twenty-five to thirty years, especially

[1] See page 68.

where they are in a position where traffic is not so severe as to wear them to any considerable extent.

The Local Government Board, for some reason or other, defines the life of soft wood for loan purposes at ten years.

But if the life of the wood paving that has been laid in London was taken, exceptionally few areas would be found where it was removed within ten years, and the average would be more probably about fifteen years On examining the table on page 69, we find only one place where the paving has been removed in seven years, and that is on a bridge having a steep gradient where the wheels are braked and skids used. The heaviest trafficked road has a life of about eleven years, the greater area of the paving has a life of fourteen, sixteen, and seventeen years, and several areas have a probable life of thirty years

The calculation of the life is based on the total wear being 2 inches, this being the average total wear of a 5-inch block before it is removed from the roadway, the rate of wear each year being measured

Cost of Wood Paving.—The cost of the paving is about 7s 6d. to 8s per superficial yard apart from the concrete, but it depends on the market price of the deals at the time the work is done.

ASPHALT PAVING.

Another class of paving which competes with wood paving and sett paving is known as asphalt. Probably this class of paving will come more into favour with the increase of motor traction.

There are various classes of asphalt, but those which have had the greatest success in this country are laid by such firms as the French Asphalt Company, the Limmer and Trinidad Lake Asphalt Paving Company, the Val de Travers Asphalt Company, and others.

Composition of Asphaltic Rock.—The asphalt that is used by these firms is from a natural rock found in France, Germany, Italy, Switzerland, and Sicily. In its original state it is in the form of an impregnated, laminated, or amorphous bituminous rock. The bitumen is in the proportion of from 4 to 20 per cent, the remaining material is composed of fine carbonaceous limestone, which is made up of the remains of marine animal life, and is of such a character that a better and more thorough impregnation is made by the bitumen than would probably be the case if the limestone had been composed of crystalline calcite.

The fineness of the mineral matter may be gauged from the fact that on an analysis it is found to contain from 60 to 80 per cent. of material passing a mesh of $\frac{1}{200}$ inch and only 5 per cent. passing a mesh of $\frac{1}{100}$ inch. It may therefore be taken that the coarse material is the

roportion that is retained by a $\frac{1}{100}$ mesh, and the fine material the nount that is retained on a $\frac{1}{200}$ mesh.

In some of the quarries the rock is found to contain too small a oportion of bitumen, and would therefore not be suitable for paving adways; but by a judicious mixture of material from those quarries here the stone is found to be richer in bitumen, or by adding fficient bitumen such as that from the Trinidad Lake, a good aterial is secured, which contains about 12 to 13 per cent. of bitumen.

Treatment.—The rock as it is obtained from the quarries is broken), ground into a powder, and heated to a high temperature, it is en brought on to the job, laid to a thickness which on compression ves a net 2 inches, the compression being obtained by tamping with t heavy iron punners, the resulting surface being hard and smooth.

Mastic Asphalt.—A mastic asphalt is also used for footpath paving, ade about 1 inch thick on a concrete foundation. This material is mposed of the carbonaceous limestone in which bitumen is already pregnated; further bitumen is added, together with a comparatively ge quantity of clean sharp grit and sand. Mastic is also used for ofing and damp-proof courses, etc.

Cleanliness of Asphalt.—Asphalt paving is more noisy under traffic an wood paving, but, on the other hand, it can be more satisfactorily ansed. It is not too popular with horse-owners, as it is considered be too slippery, and in a drizzling rain it is difficult to traverse its face with a full degree of comfort. Up to the present no treatment s been found to make it less slippery, but at the same time horses n become accustomed to the surface.

Weather Effect.—Very hot weather affects the material, but not to y unsatisfactory degree; it occasionally creeps and forms slight lumps, d although these may not be noticed by the casual observer, it is de apparent in the wear of the substance.

Trinidad Lake Asphalt.—This material is laid by the Limmer and inidad Lake Asphalt Paving Company, and is an artificial paving de with Trinidad Lake bitumen and finely graded sand, etc., proportion of fine material passing a $\frac{1}{200}$-inch mesh being about per cent. Thus the surface, being coarser than the asphalt, is not ite so slippery as the natural asphalt. There is no concrete, because asphaltic concrete is used which is laid about 3 inches thick, and on s is laid the above surface mixture about $1\frac{1}{2}$ inches thick, which when led gives a smooth asphaltic surface. The proportion of bitumen in mass is approximately the same as in the natural asphalt. This halt, like the other pavements of this type, is subject to creeping in y hot weather, but owing to the asphaltic concrete underneath the

movement is not so noticeable as it is where the base is cement concrete; this failing, small as it is, can be remedied by hardening the bitumen

Lithofalt.—The Limmer and Trinidad Lake Asphalt Company have also asphaltic blocks about 10 inches long, 4½ inches wide, and 1¾ inches deep. These are laid on green concrete, and cost pre-war about 4s. 9d. per superficial yard, the cost of laying being about 1s. per superficial yard extra. The pavement is known as Lithofalt

Other Asphalts.—There are other companies which make asphaltic pavings, and they are prepared to lay at cheap rates (*i e.* compared with the older companies) The material may be similar to that of the other companies, with this addition, that granite or other material is added, which, being cheaper in bulk, naturally cheapens the asphalt.

It is purely a matter of how far the proportion of bitumen to the extraneous matter can be taken without injuring the composition as a whole. The well-known companies think their material is in the proper proportion for the traffic it has to withstand, and any further addition proportionately weakens the composition. The engineer has therefore to bear these facts in mind when considering the various asphalts.

NOTE —The borough of Holborn in 1912 replaced asphalt paving with granite sett paving The reason given is that with very hot weather and their heavy traffic, the asphalt became wavy, and the depressions of the waves have so worn that repairs have had to be made although the paving has been laid only three years.

It would be unwise to condemn asphalt paving from this experience. This fault of waviness is capable of correction in asphaltic mixtures. The temperatures in 1910 and 1911 were exceptional for this country, and now that it is known, with the traffic that has to be met, the asphaltic composition will be adjusted accordingly, as has already been done in other cases.

There has been laid in Glasgow an area of granite sett paving with very fine joints (⅛ inch), obviously the edges of the setts will not be so easily broken, and the roadway should present a very fine surface over a long period of time. The surface would be good for motor traffic with rubber tires, but it is non-resilient for all other traffic, and as a pavement very expensive in first cost.

THE VIAGRAPH.

In the future it will be more necessary for the engineer to know the relative condition of the surface of a road than it has been in the past, especially if the stitch-in-time repairs are a policy that will be adopted. It will also be desirable to have the information in the form of a record to determine when the road should be renewed.

For this purpose the viagraph invented by Mr J. Brown, F.R.S., and made by Messrs Glenfield & Kennedy of Kilmarnock, will be very valuable.

It consists of a straight-edge applied continuously to the road surface along which it is drawn at a foot-pace, and carrying an apparatus

for recording on paper a profile of the road surface, and indicating a numerical index of the unevenness. These, taken together, give quite a fair estimate of the quality of the road at the part tested.

The instrument is in the form of a sled with straight runners; it can be folded so as to be easily carried

Between the runners of the sled and protected by a hinged glass cover are mounted the working parts; metal struts connect the two runners and keep them rigidly in position. One of these carries a horizontal pin which acts as a pivot for a lever. At the opposite end of this lever, which is free to rise and fall independently of the frame, is fixed a revolving road wheel. While the main frame, on being drawn along the road, preserves a sufficiently even line, the road wheel rises and falls over all the unevennesses of the surface. Through the lever this movement is transferred to a pencil, which marks the amplitude of these movements on the paper, which passes round a drum. The drum is rotated by a clockwork arrangement, and as the pencil marks are vertical the amplitude of these movements are plainly marked and proportionate to the length of the road covered by the viagraph. The gearing is so arranged that the paper moves in the proportion of $\frac{1}{8}$ inch to the foot. The vertical movement is full size. A second pencil marks a datum line. From this datum line the measurements can be taken of the rise. The sum of the depths of all these unevennesses constitutes the numerical index of unevenness,. and it is indicated on the decimal counter. This is arranged by fixing a cord to the free end of the lever, led over a guide pulley, round a grooved pulley, and attached to a stretched rubber band attached to an eye in the frame. When the road wheel and lever descends, the cord rotates the grooved pulley, the rubber band stretching to allow the necessary movement of the cord. When the road wheel and lever rise again, the cord slips back on the pulley, the rubber taking up the slack, while the pulley is held fast by a brake; thus the pulley rotates intermittently in one direction only, and the sum of the movement is indicated on a decimal counter in inches or in feet per mile as desired. The number recorded is the index of unevenness for that road, assuming the section of the road to be a fair sample. The grooved pulley may be substituted by a ratchet wheel of about 0·05 in pitch, with triple differential pawls. This arrangement gives the measure of minute unevennesses, and in consequence the number of unevenness is much higher than in the former case.

The length of road usually tested is 88 yards, and the apparatus is set so that it will automatically record that length, the striking of a bell indicating the completion of the length. The paper is removed, and a record of the time, place, etc., is written upon it.

To secure a good idea of the condition of the road, it is desirable that a series of diagrams should be taken parallel to each other, and if the positions are carefully noted, then at later periods similar diagrams can be taken over the same lines and a comparison may then be made and recorded and kept for reference. If a datum level is also recorded, the rate of wear would also be more accurately secured.

It is suggested that by means of these records payment by the State or by county councils might be made, the amount to depend on the condition of the road surface recorded in this manner; also, in cases of dispute as to the condition of the road, a series of diagrams covering the period before and at the time of the dispute would be invaluable

It will be evident that the numerical indication is not by itself a clear index as to the unevenness, as it may reach a high figure in a few holes, therefore comparison must be made with the diagram itself

The three following diagrams give an indication of the records of three different roads —

No.	1.	The sum of the ruts is			12 to 14 feet per mile.
,,	2.	,,	,,	,,	42 feet per mile
,,	3.	,,	,,	,,	134 ,, ,,

No	1	would be	considered	an excellent road.
,,	2	,,	,,	a fair road.
,,	3	,,	,,	a bad road.

It is interesting to follow these ruts as so recorded; the sum of the unevenness may be taken as representing in effect an artificial hill interposed by the bad state of the road. Taking the case of No. 3 and supposing the average sum to be 100 feet per mile, we have an artificial hill of that amount in each mile; consequently, any vehicle making a 30-mile journey on such a road has in effect to climb a hill (over and above any recognised hills on the road) made up of ruts alone. A vehicle weighing one ton and travelling 7 miles per hour would require extra power to the amount of $\frac{3}{4}$ horse-power, or 35 cwt. at $3\frac{1}{2}$ miles per hour would require the same extra horse-power. In the second case the extra power would be $\frac{1}{4}$ horse-power.

Owing to the fact that the smallness of the road wheel would enable it to find ruts which an ordinary road wheel would not fall into, a skate-shaped slider curved to a circle corresponding to a wheel of average size is used (say 40-inch diameter). This slider is attached to the via-graph by a hinged lever with a spring pressing it down on the road surface, along which it slides close to the road wheel; it works a second profiling pen and decimal counter. The index of unevenness given with the slider is naturally smaller than that from the road wheel; it

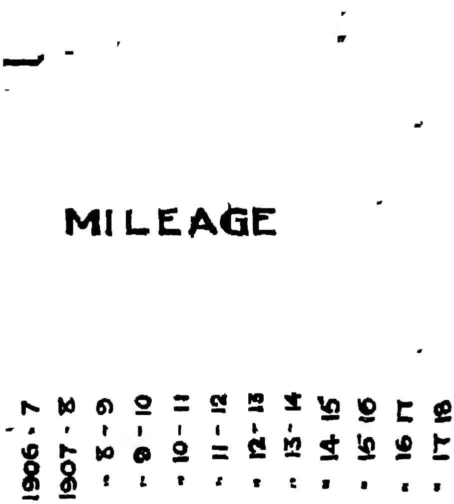

MILEAGE
1906 - 7
1907 - 8
" 8 - 9
" 9 - 10
" 10 - 11
" 11 - 12
" 12 - 13
" 13 - 14
" 14 15
" 15 16
" 16 17
" 17 18

Fig 57.

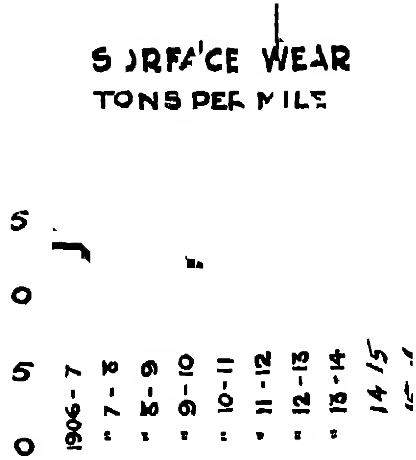
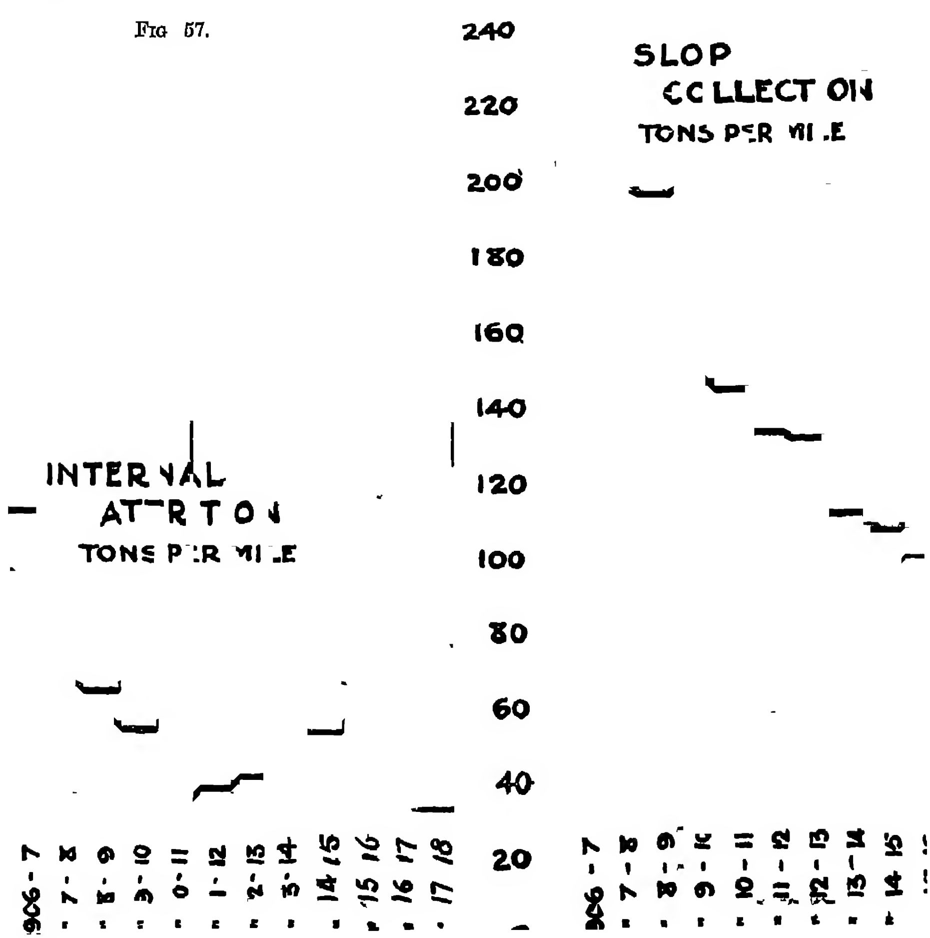

5
0
5
0
1906 - 7
" 7 - 8
" 8 - 9
" 9 - 10
" 10 - 11
" 11 - 12
" 12 - 13
" 13 - 14
14 15

Fig. 58.


240
220
200
180
160
140
120
100
80
60
40
20
SLOP
TONS
INTER
TONS

works out on a macadam road about $\frac{4}{5}$ to $\frac{3}{5}$ that of the latter. On asphalt the two counters give almost equal results

The viagraph is put forward by the inventor as useful for the following purposes :—

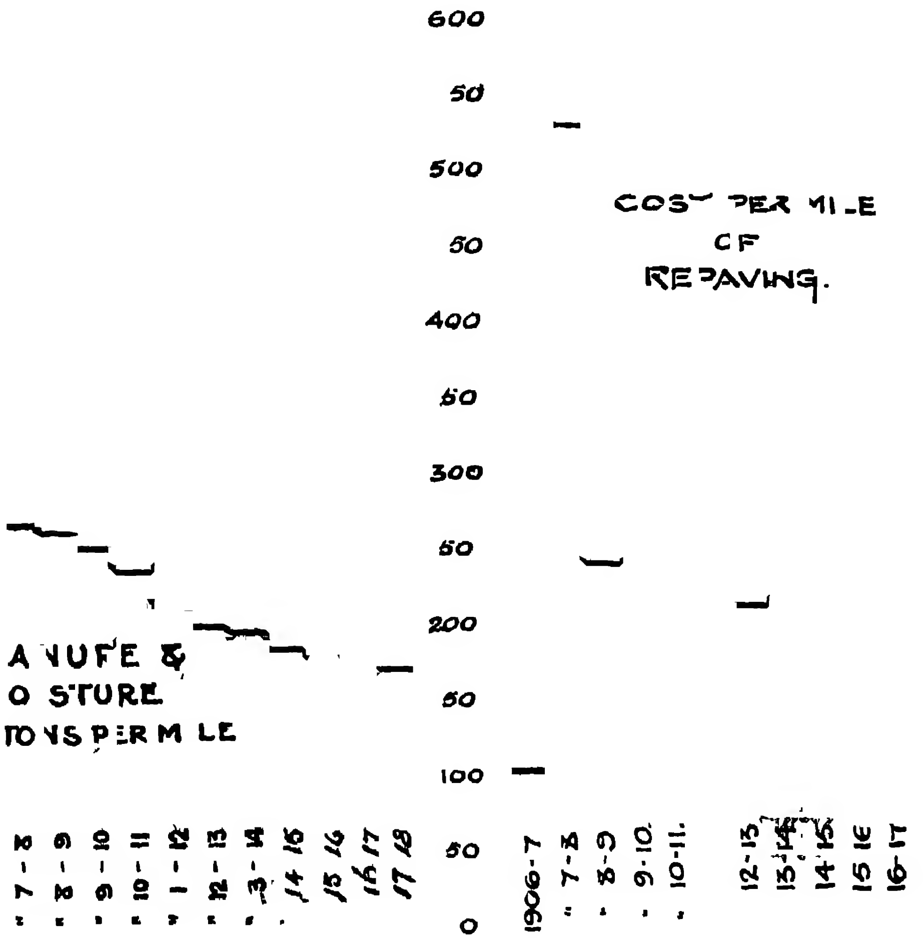


FIG. 61. FIG. 62.

1. To ascertain the condition of roads at a distance without personal inspection; any intelligent man or boy can do viagraph testing.

2. To obtain records of the surface of any road from time to time under various systems of maintenance, and so compare the relative merits of such systems.

3. To make comparisons with roads of other districts in order to

emphasise the need of more expenditure, or a different treatment in the surveyor's own district

4. To keep a check on road surveyors or inspectors by causing diagrams to be made of the road surfaces in their respective districts.

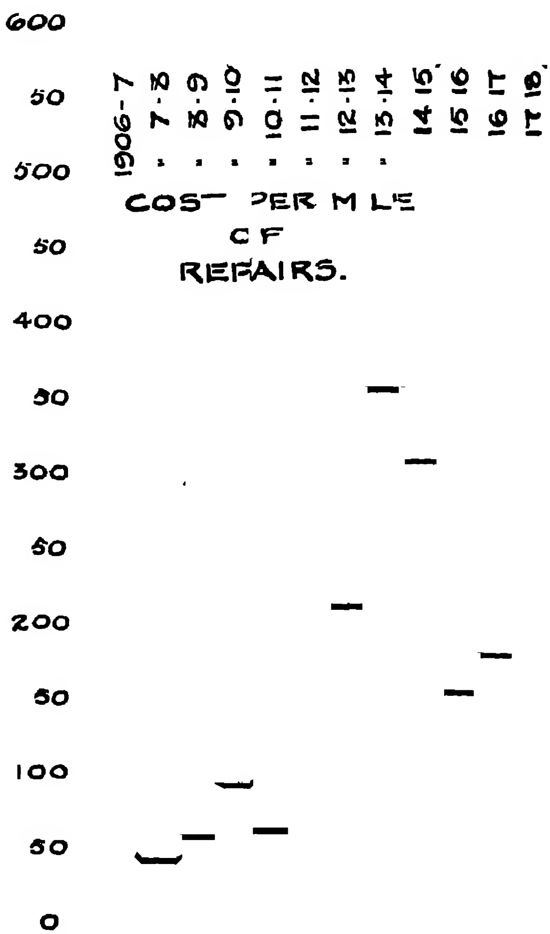


Fig. 63.

5. In actions at law where the state of the road surface is in question, to bring definite evidence of its exact condition.

6. In cases of dispute with contractors, to produce graphic evidence of the state of the road surface in support of the surveyor's contention.

7. To make contracts for the repair of roads more definite by the insertion of a clause to the effect that, when tested by the viagraph,

the surface must not show a rut or depression of more than . . . inches nor any unevenness of more than . . . feet per mile.

8. To assist in settling claims made for maintenance between county

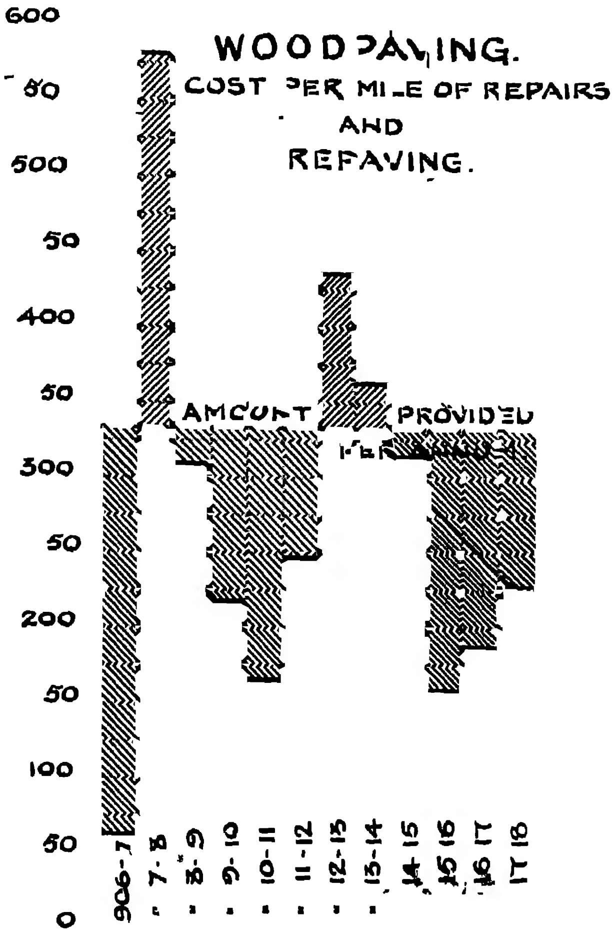


FIG. 64.

councils and other local authorities, by producing before the arbitrator evidence of the condition of any road in question.

9. To controvert complaints, if unjust, that may be made, either in the Press or otherwise, of the bad condition of any road, or to ascertain if the complaint is sufficiently well founded to need attention.

The viagraph would also be valuable to cyclists and others desirous of knowing the condition of the roads in any distant district in which

propose to travel, and to all associations or individuals who wish ıticise roads for the purpose of having them improved.

'ig 57 shows the mileage of public roads maintained in Fulham.

'ig 58 shows the amount of surface wear of these roads.

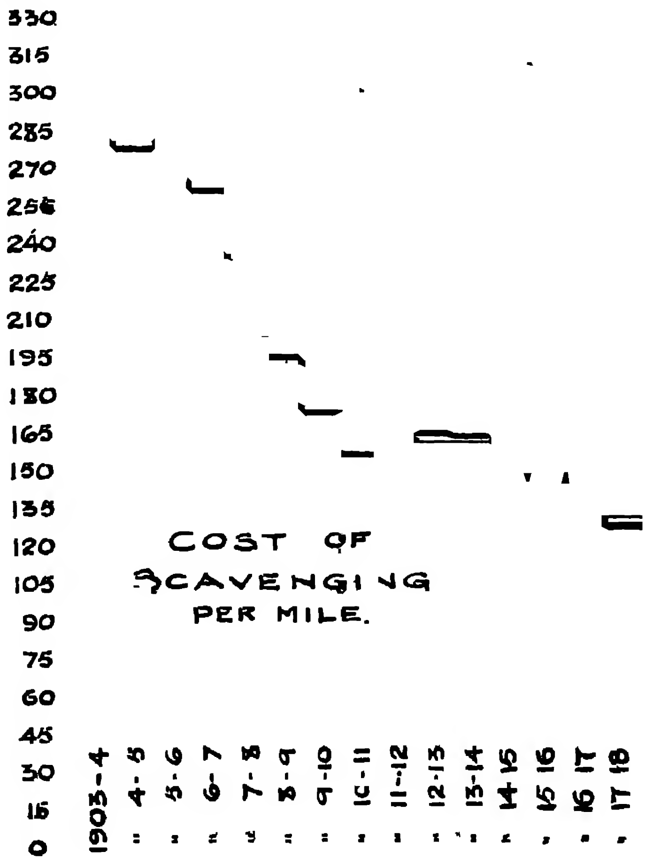


FIG. 65.

'ig. 59 shows the approximate amount of tons of grit removed as a t of internal attrition in macadam roads.

'ig. 60 shows the amount of grit, manure, etc., scavenged and carted y from the whole of the roads.

'ig. 61 shows the approximate amount of moisture in the refuse so cted.

'ig. 62 shows the cost per mile of repaving the wood-block paving, hich there is approximately 12 miles.

'ig. 63 shows the cost of the repairs to these wood-paved roads.

Fig. 64 shows the combination of the diagrams 62 and 63 and the amount provided for in the rates each year for the maintenance of the wood-paved roads.

Fig. 65 shows the cost of scavenging the whole of the roads.

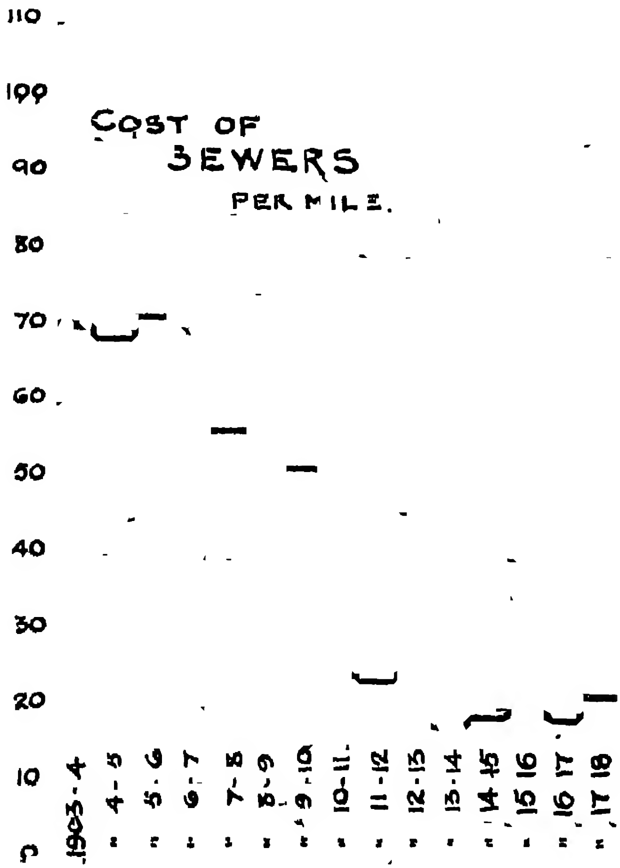


Fig. 66.

Fig. 66 shows the cost of cleansing the sewers. This is included because it was anticipated that, as the streets were rendered impervious, there would be less grit washed into the sewers. This result is actually gained, but, as will be seen, the reduction is at a later period than the date when the tar-spraying was commenced, and was more apparent in the year following the period when the bituminous roads were constructed.

Fig. 67 shows the cost of repairing the other than wood-paved roads. The cost of the roads constructed with a bituminous composition is

shown in dotted lines. The shaded lines show $\frac{1}{15}$ the cost of such construction, as it is anticipated that this pavement will be in good condition for a period in excess of fifteen years.

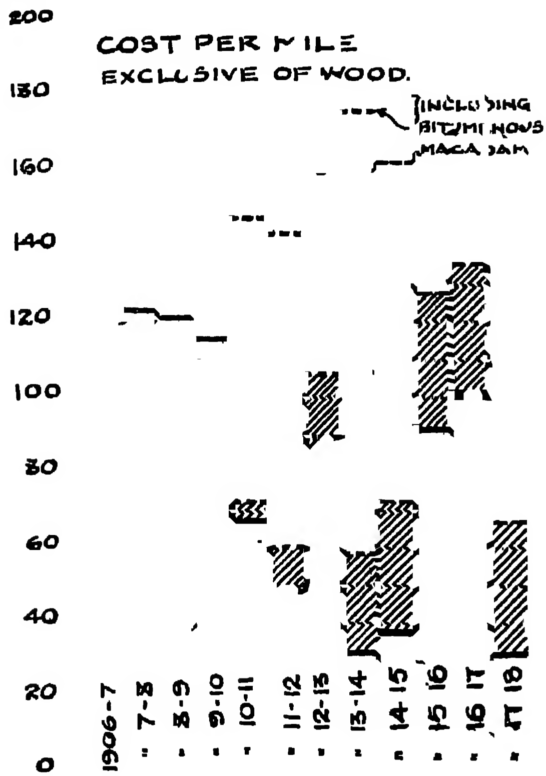


Fig. 67.

It must be taken into consideration that since 1914 the value of labour and material has increased out of proportion to the costs and values that were prevailing then.

CHAPTER XII.

COST OF MAINTENANCE OF ROADS

IN considering road-surface construction the cost of installation is an item of importance, but the cost of maintenance is of much greater importance.

Increasing Cost in Country.—During the past few years county councils and local authorities have been complaining bitterly of the increasing cost of road maintenance The complaints have, however, been confined to the areas outside large towns. Few of the large towns have complained, because they have been adapting the road surfaces to the traffic over a period of many years, and it will prove to be the case that, for example, the London boroughs are actually decreasing rather than increasing the cost of maintenance with the advent of motor traction.

There are admittedly many cases which may be considered as isolated; *e.g.* in the populous districts motor garages have been erected, and the vehicles have to traverse streets that were previously only traversed by occasional tradesmen's vehicles. In some of these garages there are from 500 upwards of motor cabs, which traverse these streets backwards and forwards several times a day, and the macadam roads are in consequence badly worn, so that it has been necessary to wood pave, asphalt, or in some other way treat the road surface to withstand the new class of traffic which has come upon these streets, and the cost for the time being has been largely increased.

Decreasing Cost in Large Towns.—But, as a whole, the streets in large towns are decreasing in the cost of maintenance, and Mr Cooper, the engineer to the Wimbledon district, shows in a chart the decreasing cost of maintenance in that borough (*Proceedings Inst. C.E*, vol. clxxxvi.), and the charts (figs. 57–67) show how the costs have decreased in Fulham; and there is no doubt that many other populous districts will be able to give evidence on similar lines. With an

alteration in the method of construction that has been suggested in these pages, there will be an equally considerable saving in the future costs of road maintenance on those now prevailing, and it would be interesting to know the effect of the tar-spraying and painting that has been done throughout the country, notwithstanding the temporary nature of such application.

Saving by Tar-spraying, etc.—The saving of approximately 6000 tons of street refuse in Fulham is represented by at least £1200 per annum in cartage and shoot costs alone. The surface must naturally be the better for the grit not being removed from the structure of the road, and must represent approximately about £2500 per annum, or about £60 per mile of road at least, which would enable a large area to be reconstructed on better lines than the water-bound macadam surface.

It has been customary in the past to scavenge the roads by manual labour, probably the most economical way of utilising this labour is to provide the man with a barrow, which is built on three wheels and can easily be pushed along the road, also a broom, shovel, and scraper. He sweeps the manure, places it in the barrow, and when it is full wheels it to an allotted place and a horsed or motor van calls at a specified time, collects it and takes it to a shoot.

Where, however, the road is composed of ordinary macadam, this method is not applicable because of the large amount of material that has frequently to be removed In these cases horsed brooms or mechanically driven brooms are employed.

The advent of motor vehicles and their popularity has reduced the quantity of manure to be collected, and where the principal roads have been constructed with a wearing surface of a bituminous character the necessity for brooms has been reduced, and it is beginning to be felt that the sweeping of the streets might be dispensed with and the more sanitary and satisfactory method of washing the roads be adopted. The amount of deposited material to be washed from the roads will be exceedingly small under such future conditions, and one of the advantages of washing is that the greasy material which is in evidence on smooth-faced roads under certain weather conditions is likely to be more effectively removed than by the ordinary method of sweeping.

Amount of Slop Collected.—In some of the London boroughs the amount of street refuse is as much as 700 tons per mile, the lowest quantity being under 150 tons per mile. The quantity depends largely on the class of traffic and its density, but that there is a large possible saving by the waterproofing of the surfaces of such roads must be very evident, and by adopting a permanent method of construction the economy will be even greater.

Reduced Cost due to Improved Methods.—In natural asphalt and wood paving we have two of the cheapest forms of surface construction over their respective lives, simply for the reason that the material wears only in proportion to the traffic traversing its surface. In the case of two-coat bituminous paving, or where the traffic is light and the one-coat bituminous surfacing mixture is used similar to that shown by analysis M on page 199, similar results will be obtained, with the greater advantage that the cost is very much less than either to instal, and is therefore available for streets with a lesser density of traffic, and where natural asphalt and wood paving would be too prohibitive in first cost. In still lighter trafficked roads tar-macadam construction will give somewhat similar results.

Census of Traffic.—While roads have been constructed on the water-bound system, there has been little or no advantage in taking a census of the traffic, because the wearing results are not dependent on the traffic, but on the traffic in combination with the weather In those cases where the weather effects are eliminated by whatever means, then the census of traffic becomes of value, and the wear and life of a road may be anticipated and judged fairly accurately.

The life of wood paving or any other paving must not be taken as the period over which a loan is given by the Government Departments, as these periods are purely arbitrary and of no value from a maintenance point of view.

Wear and Life of Wood Paving.—The wear of the best Swedish soft-wood paving is 0·027 inch per annum per 100 tons per foot effective width of roadway per day, and by taking the total wear of 2·0 inches we can obtain the life of the paving. If the road is heavily trafficked, it may be impossible or impracticable to repair the weak places, and it becomes advisable to repave at an earlier period in consequence; the wear in such a case will probably be only 1·50 inches.

Suppose the traffic is equal to five million tons per annum over an effective width of the roadway of 32 feet:—

$$\text{Life} = \frac{2{\cdot}00}{\dfrac{5{,}000{,}000}{365 \times 100} \times \dfrac{1}{32} \times 0{\cdot}027} = 17{\cdot}3 \text{ years};$$

or, if not repaired—

$$\text{Life} = \frac{1{\cdot}50}{\dfrac{5{,}000{,}000}{365 \times 100} \times \dfrac{1}{32} \times 0{\cdot}027} = 13 \text{ years}.$$

Wear and Life of Asphalt.—Asphalt paving is only 2 inches deep, and therefore the wear is only about 1 inch when it is replaced by new material; but the proportion of wear is much less than in the case of wood pavement, on account of the greater resistance of the material as compared with that of the fibres of the timber. Whereas the rate of wear per 100 tons per day per foot of width of roadway is 0·027 inch per annum in the case of wood pavements, it will only be 0·01 inch in asphalt pavements, and therefore the life, under the same conditions as in the above example, would be about 23·4 years, or about 33 per cent. longer than the life of the soft wood. When the material is laid the thickness is 2 inches, but under traffic there is compression, and it is only when the material has taken its full compression that real wear begins.

The method of laying the asphalt has therefore to be carefully gauged in order that a not too great compression is given to the material when it is first laid, otherwise wear will begin earlier than need be the case. In other cases where the traffic is not heavy, compression is more severe in the laying, but this is gained by placing only 1½ inches of material instead of 2 inches.

Reason of Unequal Wear of Wood Paving.—In the case of wood pavements the wear takes place more rapidly where the blocks are lightest or uneven in character. No amount of selection will obviate this economically. A tree grows with the stem of greater diameter at the bottom than at the top, so the fibres of the top portion are not so dense as those at the foot of the tree, there not being the same proportion of heartwood. As the deal from which the blocks are cut are of even size from end to end, if follows that one end of a deal may be very hard, and the other end, comparatively, much softer; and as the blocks cut from the deals are laid indiscriminately, it will be the case that there are areas of softer wood and areas of hard wood, or they will be intermingled. The difference is not noticeable until after about eight years of fairly heavy traffic; then small holes make themselves apparent, or areas of about 2 or 3 feet in diameter. It is for this reason that the milder timber is probably a more satisfactory wearing material, although it may not last quite so long.

Repair of Wood Paving.—The repair of wood paving under heavy traffic, as shown in the table, page 71, is about 2·6d per superficial yard per annum. The actual cost of the repairs is shown, and also the cost of such repairs spread over the total area paved; but in the cases illustrated the paving had been laid down from six to twenty-two years, and the rate of wear is due to heavy traffic equal to 5,000,000 tons per annum or 1200 tons per foot of width per day. An average trafficked

road would not be less than 500 tons per day per foot of width, and therefore the cost of the repair of wood paving on such roads would not exceed 1d. per superficial yard per annum

Thickness of Wood Paving.—The depth of the blocks is usually 5 inches, but there is no reason why 4-inch blocks should not be used in lighter trafficked roads. The method of selecting the depth of the block may be obtained by adopting a classification of roads according to the estimated traffic, 1200 tons per foot per day and over, 600 to 1200 tons per foot per day, and 300 to 600 tons per foot per day.

Assuming it to be over 1200 tons, multiply this figure by the rate of wear, say 0·027 inch, divide by the width, say 30 feet, multiply the result by 20, and add this to 3·0 inch · we have 5·16 inches; a 5-inch block would be the size required. In the case of 600 tons, the result would give 4·08 inches, *i.e.* a 4½-inch block would be sufficient; in the case of 300 tons, a 4-inch block would serve the purpose Any less depth than 4 inches off the saw would not be economical, and similarly as may be gathered, any greater depth than 5 inches would not give more satisfaction than a 5-inch block.

Repair of Bituminous Macadam.—No repair has had to be made in bituminous macadam under the writer's control, but where trenches have been cut through the material, the composition has been reheated and put back again. In those cases where it disintegrated, the surface was hacked and a surfacing mixture about ¾ inch or 1 inch thick was laid on the top of the macadam, the cost of which being about 3s. per superficial yard actually laid.

A good road structure should—

1. Have a long life—fifteen to twenty years.
2. Not need repair or attention for a period of five to seven years.
3. Give a smooth and even surface.
4. Be clean, free from mud.
5. Cause the least possible tractive effort.
6. Not cost more than 9d. per superficial yard per annum, including first cost spread over its life and yearly maintenance.
7. Be easy to repair, with little disturbance to traffic.
8. Be comparatively noiseless.
9. Submit to heavy, moderate, or light traffic satisfactorily.
10. Give reasonable foothold for horsed traffic.

In the writer's opinion the asphalt or bituminous pavement w answer all these tests in a satisfactory manner, but soft-wood pavii will hardly take second place; in fact, there are many areas where prefe ence should be given to this class of pavement. Hard-wood and ston

sett pavements, including Durax or Kleinpflaster and tar-macadam pavements, would take the third place; they each have their respective spheres, in which one may be better than the other.

The life of a road structure depends on the weight of the traffic and its volume; the gradient of the road; the climate of the locality. If it is a composition, it will depend to some extent on the human element; that is to say, there is a probability of unevenness in the laying, however careful the men may have been to ensure the best results; the weather that prevailed whilst the work was being carried out is also a factor

LAYING OF ASPHALT IN RAINY WEATHER.

It is preferable that bituminous pavements should be laid in fine weather and also when the temperature is not too low. But there is no reason to suppose that good results will not be secured if the pavement is laid in moist or cold weather. Naturally no pavement would be laid in the pouring rain As an example of what has been done, the reader is referred to an article by Mr T G Marriott in *The Surveyor*, October 18, 1918, who was responsible for the construction of 5 miles of a bituminous pavement in Oxford during eleven months of 1915 and 1916. On 182 days rain fell, and on 33 days snow fell; it was the wettest year experienced in that city for 100 years, with one exception. While the mean rainfall in Oxford is not greatly in excess of London, the winter climate is by no means a favourable one for the laying of asphalt, being for the most part damp and raw, with occasionally extremely low temperatures. He says: " On the whole, the asphalt laid in the winter months at Oxford bears favourable comparison with that laid in the summer, and the writer sees no reason to doubt the efficacy of modern two-coat asphalt constructed during moderately rainy weather. Given the essentials of a suitable sub-foundation, and particularly a well-designed asphaltic concrete base, it would seem that the wearing surface or 'topping' may be put down in any conditions of weather that the workmen engaged in laying it can tolerate. On the other hand, the prejudice of engineers against the laying of compressed rock asphalt in any but the most favourable weather conditions is probably justified by the fact that this type of asphalt is always put down in a single layer on Portland cement concrete foundation, and is somewhat absorbent of moisture until full compression under traffic is obtained.

" The difference between rock asphalt and mechanically mixed asphalt in regard to water repellancy at the time of laying is sharply brought out by a laboratory experiment the writer recently carried out. A small amount of each kind of asphalt was taken in a loose condition and agitated

in an equal quantity of water for 30 seconds in a test tube The rock asphalt (Sicilian) contained 10·5 per cent. of soluble bitumen. The mechanically mixed asphalt contained 11·7 per cent. of soluble bitumen (Trinidad). After agitation, both samples were allowed to filter for 1¼ hours. At this point the rock asphalt contained 67 per cent. of moisture, and the mechanically mixed asphalt 29·9 per cent. The samples were then placed in an air bath at 220° F for half an hour. It was then found that the mechanically mixed asphalt had thrown off all its moisture with the exception of 2·5 per cent, while the rock asphalt powder still held 29·8 per cent. Thus it will be seen that not only was the rock asphalt in this condition more absorbent of water, but that it gives off its moisture more slowly than the mechanically mixed asphalt.

"These conclusions are in no way intended to impugn the quality of compressed rock asphalt. On the contrary, the writer believes this type of construction to represent the highest standard of asphalt paving for heavy traffic. It is merely intended to put forward reasons why the prejudice of engineers against the laying of rock asphalt in rainy weather need not extend to the modern two-coat mechanically mixed asphalt. This latter form of asphalt, consisting as it does of fine particles coated with an adhesive film of bitumen, is obviously more water repellent at the time of laying than rock asphalt powder with its light impregnation of bitumen, and thus lends itself more readily to successful application during rainy weather. Moreover, in the two-coat work the bottom layer of asphaltic concrete or binder acts as a key for the wearing surface or 'topping' even when rain is falling, and also serves to a large extent to drain away any surface water."

This is the personal opinion of one who has a wide knowledge of bituminous pavements and almost a unique experience in the laying of that pavement in all parts of the country under very variable weather conditions.

The author has been himself impressed with the latitude that can be given in the laying of the material, but he cannot wholly accept the position that it is not detrimental to the structure to lay it in any conditions of weather that the workman can tolerate. Strictly, a man will tolerate any conditions if he is paid sufficiently well. There must be a limit, *i.e.* a rain limit. The topping should not be laid on a wet surface, so wet that the heat of the asphalt topping is unable to properly evaporate the moisture on the base-coat in advance. If the moisture is not evaporated but is simply heated so that it forms steam which cannot get away, and as soon as the asphalt topping is cold the steam condenses back to moisture, the moisture will prevent adherence to the base, or permeate the topping mixture to its eventual detriment. Probably on

a lightly trafficked road, or one that is submitting to a moderately heavy traffic, the effect would not be noticeable for a few years, but that it will eventually tell in the structure is almost certain. There is a difficulty which should not be lost sight of, and it is that the plant, where the material is being manufactured, may be some distance from the road that is to be constructed, and the weather may be fine and satisfactory during the time the material is passing through the works, but when it arrives on the job it may be raining heavily. If the work was not allowed to be proceeded with on account of the conditions of the weather, the difficulty of dealing with the material would be great and costly, because, as soon as it is cold it sets like concrete, and special arrangements would have to be made to break it up and reheat it. This, however, ought to be provided for; the base should be covered with tarpaulins or a weather-proof covering sufficient to enclose the length of roadway that is to be coated with the mixed material, and advantage taken of any subsidence of the rain to lay it in position.

APPENDICES.

APPENDIX I.

SIDCUP TRIALS.

THE Road Board in 1911 made a series of experiments at Sidcup. The object which the Board had in view was to secure a service test, under uniform conditions, of a number of trial lengths of roadway laid down under the general direction and supervision of the Advisory Engineering Committee of the Board, so that a record of comparative results could be obtained in a better and more reliable manner than is generally obtainable in the case of road surfaces laid down in the ordinary course of road maintenance in different parts of the country.

The scheme for laying down the trial sections was framed so as to secure that they shall be constructed and maintained in precisely the same manner as road-surface work laid down under normal service conditions, except that the cost of the work is to be provided by means of a grant from the Road Board, and the entire work of construction and maintenance was to be subject to the general supervision of the Advisory Engineering Committee of the Board.

The choice of the road to be used for experimental work was the subject of careful consideration. It was desired to get a road on which the experience gained might be practically applicable to any macadam road having to carry a fairly heavy traffic, whether in town or country, but it was difficult to find a road of what may be described as average conditions. The traffic on the road selected is much heavier, both as regards its kind and its quantity, than most roads have to carry, and the trials therefore provide an unusually severe test; but it was thought that it was better to have a road the traffic on which was above rather than below the average, and that the results of the trials would be fairly applicable even to roads of lesser traffic density, in so far as they would indicate the comparative efficiency and durability of the methods tried.

It was also thought desirable that the road selected for the first trials should be in proximity to London, where it would be generally accessible, thus enabling the greatest number of road engineers throughout the country to inspect the work.

The Sidcup scheme as carried out includes a total length of carriageway of 2490 lineal yards and a superficial area of 18,420 yards.

A summary of statistics of traffic on the New Eltham-Sidcup road for the week ending 13th September 1910 was given, and the total weight of traffic passing over the road amounted to 2518 tons per day.

Another traffic census taken for the week ending 21st August 1912 gives 3547 tons per day, an approximate increase of 41 per cent.

It should be noted that the cost per yard as stated (except in the case of the lengths laid by the Kent County Council) were the amounts paid to the contractors for small lengths laid under expensive conditions, and could not therefore be used as indicating the cost of laying the various materials in large quantities under average commercial conditions.

The cost of scavenging the twenty-three sections for a complete year is returned by the Kent county surveyor (1913) as £127, 8s. 3d., being at the rate of £84, 18s. 10d. per mile

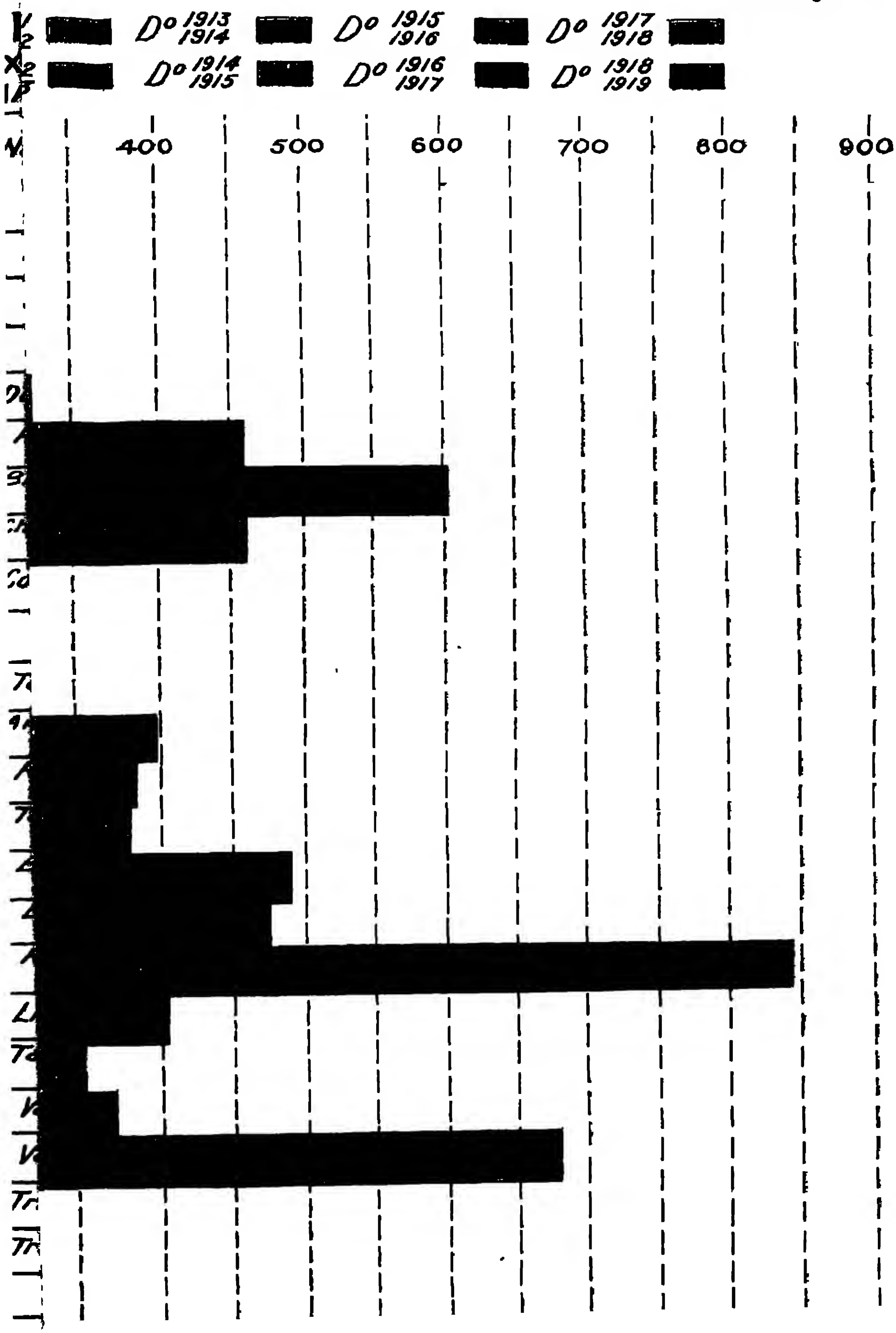
The facing chart, which has been prepared by Mr H. T. Chapman, M.Inst.C E, the county surveyor of Kent, gives in a graphic form the original cost and the cost of repairs for each year until 1918. The life of the various pavements is not exhausted, and the final cost per annum over the complete life will not be determined for some years, except in a few cases where reconstruction has been carried out but the figures are interesting, and the author makes the few following comments which seem to be pertinent.

In several cases the original cost includes the free maintenance of the area for a period of five years, and very naturally the cost would include a figure which would cover the maintenance for that period.

Durax on pre-war prices would probably have been laid at a cost of about 5s. 6d. per superficial yard if it had been done direct by the local authority. The cost per superficial yard per annum would therefore have been at a much lower figure than is indicated in the diagram Section 23 cost originally 7s. 6d., but this has been done by other authorities at 4s. 6d., and the cost of maintenance being the lowest, would have also placed this section in the best position with Durax so far as the cost is concerned.

Another pavement called Roadamant, at 9s. 3d., seems very high; it includes a concrete foundation. It is a form of mastic asphalt, and mastic asphalt has been laid about 1 inch thick on an old macadam road surface at 3s. 9d. per superficial yard. There are instances where it has worn

To Face Page 252.



exceedingly well, and though this section seems to have failed, there was probably a fault in the composition; it should not be condemned in principle by this example.

There are several sections that have been experimentally treated with bitumen carpets which have apparently failed. Here again it is undesirable to condemn this carpet system, because section 14 has been reconstructed with this bituminous mixture and is wearing apparently very well, and the cost of maintenance has been small; thus the bituminous carpet is worth testing still further, and especially so when section 23 has a bituminous carpet also.

In the writer's view section 23, 5, and the reconstructed No 14 show the best results to date.

The next in merit seems to be section 3, but there are varying results of the single-pitch grouting. Sections 1, 2, and 8 have been reconstructed with this material, and their first costs, 2s 6½d., 2s. 1½d., and 6s. 3d. respectively, compare with 4s. 1d , the cost of section 3. But Mr Chapman informs me that 50 per cent. of old material was used in section 2 and 25 per cent. in No 1, whereas there were water difficulties to contend with in section 8 , probably the 4s 1d. was a fair representation of the cost of each on a "new" material basis. But, as will be observed, the cost of maintenance of each of these sections varies considerably, sections 1 and 2 being about double that of Nos. 3 and 8

The next in merit appears to be slag tar macadam, the two-coat pavement being superior to the single coat This would point to the improvement which is secured by using finer material in the surfacing; the cost of maintenance, however, of this form of construction seems heavy in sections 9 and 17. The maintenance costs of sections 7, 13, 15, and 16 are low, but they have only been reconstructed about two years, so that a comparison is scarcely ripe.

APPENDIX II.

EXPANSION OF MATERIALS.

Coefficient of Expansion.	K. per F.
Gasoline	0 0005
Creosoting oils	0 00044
Fluid residual petroleum	0·00039
,, tars	0·00033
Asphalt cement	0·00030
Heavy refined tars	0·00030

APPENDIX III

SPECIFICATION OF WORK TO BE DONE AND MATERIALS TO BE EMPLOYED IN CONSTRUCTING A NEW STREET.

1. **Kerbing.**—The new kerb is to be 12 inches by 8 inches Norway granite, the best of its kind, of a uniform scantling, true and straight, free from all imperfections.

No stone is to be less than 3 feet 6 inches in length when delivered on the works, properly squared and tooled on the face, the full depth of the front, and 3 inches at the back, and to be dressed at right angles to the face, and with an underside that will bed evenly on a good foundation of Portland cement concrete as per Clause 9.

The circular kerb to be of the same quality and description and accurately worked to the required radius.

2. **Channelling.**—The channelling, except where otherwise specified, to be formed with 12 inches by 6 inches Norway granite of the best quality, true and straight, of uniform scantling, free from imperfections of every kind; no stone to be less than 3 feet 6 inches long, properly squared, dressed and tooled at right angles to the face, with an even underside, so that it will bed evenly and solidly on the concrete, the stones to be laid so as to break joint with the kerb. The circular stone to be of the same quality and description, and accurately worked to the required radius.

3 **Crossings.**—The setts used for crossings of roads and gateways to be 4 inches by 4 inches by 4 inches Enderby, Harboro', or other approved granite, properly squared and dressed to an even and regular face, and laid with broken joints.

4. **Bricks.**—The bricks required are to be good, sound, hard, and well-burnt stock bricks of a uniform size and shape.

5. **Cement.**—See specification for wood paving.

6. **Flints.**—The flints for covering the road, if used, are to be procured from the neighbourhood of Sittingbourne, Kent, and are to be well screened, free from loam, and of the best quality; no stone shall measure in any dimension more than 3 inches.

7. **Sand.**—See wood-paving specification.

8 **Thames or Pit Ballast.**—See wood-paving specification.

9. **Cement Concrete.**—See wood-paving specification.

10. **Blue Lias Lime Concrete.**—The blue lias lime concrete is to consist of 6 parts of pit ballast and 1 part of blue lias lime of an approved quality (the parts being ascertained by measurement of their volume

in proper measures), twice turned over and thoroughly mixed togethe in a dry state on a timber stage not less than 10 feet by 10 feet for hal a cubic yard of concrete ; water is to be added (through a rose if re quired), and the whole again twice turned over until a proper con sistency is obtained. If the concrete has commenced to set before bein used, it is not thereafter to be used except as ballast.

11. **Cement Mortar.**—The cement mortar is to be composed of part of cement to 2 parts of clean, sharp sand, mixed on a prope banker, as previously described for the concrete, and used while fresh.

12. **Mortar.**—The mortar is to be composed of 1 part of blue lia lime or grey-stone lime and 2 parts clean sharp sand, the whole to b mixed on a proper banker whilst the lime is hot, and immediately afte slaking.

13. **Cement Grout.**—See wood-paving specification.

14. **Hard Core.**—The hard core is to be composed of brick rubbis (free from mortar, wood, shavings, or paper) or other approved material and is to be of not less size than 3 inches in any measurement.

15. **Hoggin.**—The hoggin is to be of the best binding quality, fre from loam, clay, or earth.

16. **Stoneware.**—All pipes, bends, syphons, junctions, etc., are to b of the best hard, well-burnt, glazed stoneware, free from flaws or crack All pipes are to be laid with a regular fall, and carefully jointed wit neat Portland cement, and where required the pipes are to be bedde in and surrounded with concrete.

17. **Macadam.** The macadam is to be of the best Guernsey granit free from dirt or any earthy matter ; it must be sharp and evenl broken, of a size to pass through a 2-inch ring ; the stones must b reasonably cubical, and should the borough surveyor be of the opinio that the macadam is inferior in quality and has an undue proportio of small, thin, or flat stones, it will be rejected, and such material mus be removed from the site of the works forthwith.

The macadam is to be carefully and evenly spread upon the surfac of the hard core in two layers, each layer to be 3 inches in thicknes when consolidated, and to be properly slopped in with material de scribed above and thoroughly rolled.

The contractor is to deposit a sample of the macadam he propose to use upon the road at the borough surveyor's office, previous to th signing of the contract.

Execution of Work.

Setting Kerb.—All kerbstones are to be properly laid on a goo foundation of Portland cement concrete, as previously described, 1

inches wide and 6 inches thick, the ground to be excavated to the necessary depths and widths, and an even and regular bottom formed with a cross-fall of ½ inch towards the channel, and in such lines and in such positions and levels as the surveyor may direct.

Channelling.—The channelling to be formed with 12 inches by 6 inches Norway granite, as before described ; the ground to be excavated to the necessary depths and widths, and an even and regular bottom to be formed to the falls and levels given, a bed of Portland cement concrete, as before described, to be laid 12 inches wide and 6 inches deep, on which the granite channelling is to be laid and well bedded while the concrete is in a mastic state. The cross joints and those next the kerb to be well flushed up with cement grout ; all traffic to be kept off the channel for forty-eight hours after its completion The highest point in the channel to be $\frac{1}{12}$ inch below top of kerb, and an even and regular rate of inclination to the gullies is to be given to the surface of the channel.

Crossings.—The crossings of roads and gateways are to be formed of setts of the sizes previously specified, and on the widths shown on drawings They are to be laid on a foundation of 6 inches of concrete, on which sand is to be laid ½ inch in thickness, on which the granite setts are to be laid in courses and straight lines, and the joints filled with cement grout, and properly rammed to a solid bed with a regular curve to the channels The traffic of all kinds is, as far as possible, to be kept off crossings for four days after they are completed. A course of 7 inches by 5 inches by 12 inches dressed granite setts is to be laid as a binding course on both sides of street crossings.

Footways.—Excavate and cart away earth from footways and between kerb and back line (average width 6 feet) to an exact depth of 5½ inches below the finished surface of paving. Two inches and a half of clean clinker ashes are to be laid on the prepared foundation, and well rolled to receive paving slabs.

Any York stone required for paving the footways is to be new white York stone of a full and uniform thickness of 2½ inches throughout, to be sound and hard, of a uniform and close texture, free from sand holes, flakes, laminations, and other defects, and to dry after rain of a uniform light colour. Each stone to be properly dressed to a level and true surface, and the joints to be tooled square

No new stone is to be of a less area than 4 feet super, and shall not measure less than 1 foot 8 inches in its smallest dimension when delivered on the works.

The artificial stone to be of the best of its kind, of a uniform thickness and size, the stone to be sound and hard, with sharp arrises, free

from imperfections of every kind. No stone will be accepted which has been in stock for a less period than six months The stone will have to sustain a load of one ton between supports, 2 feet apart, without breaking or showing any signs of fracture. The stone for testing will be taken from the works, and should 5 per cent. of the stones so tested not hold out to the above requirements, the whole of the stones, of which these test stones form a sample, will be condemned, and must be taken off the ground immediately upon notice from the surveyor.

The grout for the artificial stone is to be composed of equal parts of blue lias or grey-stone lime and water well mixed together.

Carriageway. The whole of the present surface of the carriageway is to be cleared of mud, slop, and dirt, and excavated to the required depth below the level of the finished surface of the road. The excavated material is to be screened through a sieve of 1-inch mesh, and the residue, if suitable, and which may be defined as hardcore (see Clause 14, p. 255), used as hardcore topping in such places and thickness as the surveyor directs. The material passed through the sieve is to be moved from the works by the contractor.

A trench at least 20 feet long and the full width between kerb lines is to be kept clear of hard core during the progress of the excavation.

Hardcore is to be spread over the carriageway to a depth of 12 inches when consolidated by rolling, and the surface so formed is to be rolled until consolidated, or as may be required by the surveyor.

The surface of the hardcore is to be covered with two layers of macadam, as previously described, each layer 3 inches thick when consolidated by rolling, and a steam-roller, of not more than twelve tons in weight, is to roll each layer until the whole is consolidated, before chippings, hoggin, or water is added. Granite chippings are then to be spread over each layer, the last to have also a small quantity of hoggin, and water added so as to make a grout, which is to be swept into the spaces between the stones until they are filled. During this operation the steam-roller is to roll the surface until the mass of broken stones and grout is thoroughly consolidated, and the finished roadway in centre is not to be more than 4½ inches above kerb level.

The carriageway so formed is then to be as far as possible protected from traffic for three clear days after it is finished, or for a further time if required. The contour of the carriageway when finished shall be evenly and regularly curved to the levels given from the channel against the face of the kerbstone on either side to the centre of the carriageway, as shown on detail drawing.

The gullies to be stoneware gullies of an approved type, with dished bottoms, 1 foot 6 inches diameter inside, and 4 feet deep from the top

of the gully. Each gully will be tested by filling with water, and those that leak or have any other defects will be condemned and must be taken off the works at once. They are to be set and surrounded in cement concrete 6 inches thick, as previously described, and to be fixed while the concrete is in a plastic state, the finest of the concrete to be selected for this purpose, and no concrete with large stones will be allowed to be used.

The iron gully gratings, as per detail drawing, or of an approved make, to be provided and fixed and well bedded in cement, care to be taken that it has a true and even bearing on the York stone; the stone must nowhere come in contact with the stoneware gully; the outlet or swan's neck to be bedded in concrete, as shown on detailed drawing.

Excavate for and fix in the side of sewer, where necessary, a 6-inch block flap-trap, and connect from same to swan's neck with 6-inch pipes jointed in neat cement, and provide and fix all necessary pipes, junctions, and bends. The whole to be carried out according to detail drawings, or as directed

Make good the levels of the foot and carriageways of the adjoining streets so as to conform to the levels of the new work; if necessary, relaying the adjoining portions of the kerb, paving, channelling, etc., and providing new materials required to supply any deficiency.

The whole of the works, on completion, are to be cleared from rubbish, and all other things used on, or arising from, the execution of the work, shall be cleared away, and the work left in a clean, neat, and tidy condition.

SPECIFICATION OF WORKS TO BE DONE AND MATERIALS EMPLOYED IN CONSTRUCTING WOOD-PAVED ROADWAY.

1. **Sand.**—The sand is to be pit or Thames sand of the best quality, clean and sharp, and free from loam or clay.

2. **Thames Ballast.**—The Thames ballast is to be clean, the stones are to be regular in size, and the proportion of sand to stones is to be to the satisfaction of the surveyor

3 **Cement.**—The cement is to be best Portland cement, complying with the British Standard Specification, of a pale grey colour, specific gravity of not less than 3·15, or 3·10 one month after grinding, and capable of sustaining an average tensile stress of not less than 400 lbs. per square inch of sectional breaking area seven days after gauging and immersion in water twenty-four hours after gauging, and 500 lbs. per square inch of section twenty-eight days after gauging, and is to be

delivered into the works in sacks, weighing 200 lbs. net, marked with the manufacturer's name. It is to be ground so that, when sifted in a sieve of 5776 meshes to the square inch, there shall not be a residue of more than 3 per cent. Sufficient cement is to be stored in or near the works for a fortnight's use fourteen days before the commencement of the work, and an equal quantity is to remain stored during the progress of the work until only sufficient work remains to be completed to use up the cement stored during the work. The cement will in all cases be tested by the surveyor with Adie's testing machine, and the average taken of at least six tests, and any rejected by him is to be at once removed from the work without any question being raised.

4. **Concrete.**—The concrete is to consist of 1 part of Portland cement and 6 parts of clean Thames ballast (large stone to be in no greater proportion than 60 per cent.), the parts being ascertained by measurement of their volume in proper measures, thoroughly mixed together in a dry state on a timber stage not less than 10 feet by 10 feet for half a cube yard of concrete; water is then to be added from water-can through a rose, and the whole again thoroughly mixed until a proper consistency is obtained. If the concrete has commenced to set before being used, it is not thereafter to be used except as ballast.

5. **Cement Grout.**—The cement grout is to be made of 1 part of Portland cement, as described, and 3 parts of clean sand (the parts being ascertained by measurement of their volume in proper measures), thoroughly mixed together in a dry state on a proper banker, and made as previously described for concrete.

6. **Cement Mortar.**—The cement mortar is to be composed of 1 part of Portland cement, as before described, and 3 parts of clean, sharp sand mixed on a proper banker, as previously described for the concrete, and used while fresh.

7. **Thames Ballast for Top Dressing.**—The Thames ballast for top dressing is to be crushed and then screened through a ⅝-inch mesh sieve.

8. **Excavation.**—Excavate the whole of the carriageways as directed, including crossings, channellings, etc., wherever necessary, to the proper depths and levels as required, carefully separate the macadam, set aside for re-use, fill into contractor's carts, and deposit where directed within a radius of one mile from the job.

9. **Strip Roads.**—Carefully strip roads of all old wood blocks and cart away to wharf, depot, or where directed.

10. **Existing Channel.**—The existing granite kerb, or sett channels, paved areas, binding courses, crossings, and concrete under, where described or necessary, is to be taken up and carted at the contractor's

expense to the wharf, depot, or as directed. So much of the existing kerb as approved by the surveyor is to be set aside, rejointed, and relaid on Portland cement concrete 6 inches thick, making out with new 12-inch by 8-inch kerb to be obtained from the Borough Council.

11. **Floating.**—The surface of all existing floating is to be picked perfectly free from all pitch, asphalt, old floating, soft concrete, etc., in such a manner that the new floating will not alter the existing contour or increase the height of existing foundations unless otherwise directed; the same is then to be brushed clean and free from dust, well drenched, and finished with a floated surface, ⅜ inch in thickness, composed of 1 part Portland cement to 3 parts sand, as described for cement grout. The surface of new concrete to be finished in a similar manner with proper and approved contours and with satisfactory falls to gullies. The finished level of this surface to be exactly 5 inches below and parallel to the intended surface of the wood pavement. All floating after completion to be left exposed for seven days or longer, as considered necessary by the surveyor.

12. **Laying of Wood Blocks.**—After the rendering specified above has been laid sufficiently long to become thoroughly hard and set, it is to be brushed clean, the block to be dipped in a hot mixture of pitch and creosote, or anthracene oil, and then to be quickly laid in position, butt-jointed, and in parallel courses across the road.

13. **Wood Blocks.**—The timber from which the blocks are to be cut shall be carefully selected fourth Swedish, close-grained, yellow deals, bearing the shipper's mark, and which must be described in the current *Timber Trades' Journal List*. The blocks shall be of uniform size and weight and uniformly cut. The timber shall, before being cut, be submitted to the surveyor or his representative, and no blocks shall be sawn from timber of which the surveyor or his representative has not signified his preliminary approval. Four samples sealed and marked with the contractor's name and shipper's marks shall be left at the surveyor's office for his examination with the tender, and any blocks which may be brought on to the works and which may be inferior to these samples may be rejected by him. The surveyor or his representative shall have full power to reject any blocks, either at the cutting yard or at the creosoting works, and he shall also have power to reject any blocks after delivery on to the site of the proposed works, or at all or either of these places, whether creosoted or not, or which are not creosoted in a satisfactory manner, or to the extent of 10 lbs. of creosote to the cubic foot of timber, or with a satisfactory quality of creosote. The blocks when cut shall be truly square and shall measure 9 inches by 5 inches by 3 inches off the saw. The annular rings shall not be less

than 10 to the inch, not more than 2 inches of sapwood shall appear in any block, and the percentage of such in bulk shall not exceed 15 They shall also be free from large, loose, or dead knots, shakes or other defects, and shall not contain more than 5 per cent. of waney edges Timber that has not been properly stored and become dry will not be accepted. Care must be taken to prevent the blocks from becoming wet, as any in such a condition, either from rain, bilge water, or other causes, must not be creosoted.

14. **Creosoting.**—The Council shall appoint a representative to examine the blocks, who shall have power to cause the blocks to be spread on the ground before being creosoted, and to cut or mark as arranged by the surveyor any block he may reject. The blocks after being approved may then be creosoted, a sample lot with each charge being weighed both before and after the process. The creosote to be forced under pressure into them until they have absorbed an amount of 10 lbs. to each cubic foot, and in such a manner that any block split open will show the creosote to have penetrated right through.

15. **Creosote.**—The creosote is to be a liquid heavy oil of tar, commonly called creosote, and is to contain not less than 8 per cent. of tar acid. It will be subjected to analysis, and the contractor is only to use such as may be approved by the analyst.

16. **Expansion Joint.**—The contractor shall provide wooden battens 1½ inches wide by the depths of the blocks, which shall be used in the channel against the kerb, and the blocks shall be paved up to it. After the paving has been grouted in, these battens shall be withdrawn and the space left shall be filled in with clay and gravel as directed.

17. **Examination of Blocks.**—After the wood blocks are in position they will be examined by the surveyor, and no portion of the paving is to be grouted in with either the asphalt or cement until this examination has been made and sanction given for the grouting to commence.

18. **Composition between Joints.**—Approved pitch or bitumen is to be heated and run between the blocks to a depth of 3 inches as directed.

19. **Cement Grouting.**—The blocks are then to be grouted with cement grout until the joints are thoroughly filled.

20. **Protect for Forty-eight Hours.**—After the completion of the grouting the work is to be protected for at least forty-eight hours before the road is thrown open for traffic.

21. **Crossings.**—At the intersection of other streets the crowns of the adjoining streets are to be adjusted to run into the crown of the roadway that is being paved for that purpose, and whenever it may be necessary, the existing roadways or part or the whole of the crossings to the adjoining streets are to be taken up and relaid with similar

materials or with new blocks as directed, making good with new where necessary in the opinion of the surveyor without any extra charge over the amount of the contract At such intersections the wood blocks are to be laid diagonally, as may be directed by the surveyor.

22 **Binding Courses.**—Two courses of 7 inches by 5 inches by 3 inches granite setts laid on 6 inches concrete are to be laid as a binding course wherever the wood pavement would otherwise abut against a macadam road. The contractor may retain, re-dress, and re-use sufficient of the old setts on the works for this purpose as approved by the surveyor.

23. **Two Coatings of Siftings.**—After the road has been inspected a coating of ⅜-inch crushed ballast for top dressing as specified is to be spread over the wood pavement, and the pavement is to remain fenced in as described, before the road is thrown open to the traffic. An additional coating is afterwards to be spread over when directed.

24 **Facilities to be afforded for Traffic and Passengers.**—The work shall be done at such times and in such portions as the surveyor shall direct, and the workmen shall at all times afford such facilities for local traffic or the convenience of shopkeepers as may be directed by the surveyor.

25. **Wood to be laid to Proper Falls.**—The contractor must lay the blocks to such levels as are sufficient to satisfactorily convey away all water that may collect on the surface and in the channels at any time, and the work will not be taken over by the Council until this is done to the surveyor's satisfaction.

26. **Contingencies.**—Provide the sum of £   for contingencies. This sum to be deducted in whole or part from the contract as may be directed. The contractor must fill in the annexed schedule so far as the items refer to any portion of this contract.

27. **Incidental Works.**—The contractor's price per superficial yard for supplying and laying wood blocks 9 inches by 5 inches by 3 inches off the saw is to include for all necessary cuttings, raising manhole tops, ventilators or other covers, stop-cock boxes, gully tops, making good to existing wood paving, relay crossings, binding courses, and all works incidental thereto and necessary in order to leave a perfect and satisfactory job.

SPECIFICATION OF WORKS TO BE DONE AND MATERIALS TO BE SUPPLIED IN CONSTRUCTING A TWO-COAT BITUMINOUS PAVEMENT.

Materials.—As described in previous specifications.

Kerbing, channelling, footways to be carried out in accordance with the methods described in previous specifications.

Foundation of Carriageway.—The substructure to be composed of dry hard material capable of supporting a steam-roller weighing 10 tons, with driving wheels of a tire width of 15 inches, without leaving an impression of its track on the surface. Any soft permeable material to be removed to a depth of at least 6 inches, and replaced with broken stone, hardcore, clinker, or other suitable or approved material.

Base Coat (or Binder Course).—Upon the surface so provided is to be placed a coat of bituminous macadam (or asphaltic concrete) laid 3 inches thick, the centre of the road to be brought to such a level above the channel as to allow a fall from the centre to the channel at the rate of ⅜ inch to the foot.

The bituminous material is to be brought to the road in a hot condition, laid whilst still hot, and subsequently rolled with a steam-roller (described above). The roller is not to be taken on to the material whilst it is very hot, but not at such a late period that the composition has so cooled as not to allow of proper compression, and thus render the rolling ineffective. Generally the rolling should be continuous with the laying, but at a distance away.

The material must be rolled longitudinally and cross-rolled.

The surface of the rolled composition is to be kept as clean as possible, no traffic of any kind is to be permitted upon it.

If the composition whilst it is being rolled shows signs of cracking or waves under the roller, the substructure is defective and the section must be removed together with the substructure and replaced with hardcore or concrete and the section replaced with the bituminous composition.

Composition of the Base Coat (or Binder Course).—The aggregate to be composed of suitable hard-stone clinker or a combination to be approved by the engineer. The size of the material varies: 50 per cent. must pass a 2¼-inch mesh sieve and be retained on a ¾-inch mesh sieve, 30 per cent. must pass through a ¾-inch mesh sieve and be retained on a ¼-inch mesh sieve, the remainder to be sand and fine dust.

This material must be heated to a temperature of about 425° F. and then taken to a mixer—the temperature at the mixer to be about 325° F.; here it must have added to it about 8 per cent. of a prepared bitumen or tar which will have a penetration of approximately 120 at 60° F.

Composition of the Tar, etc.—The tar-binding agent will be approximately composed of—

Dehydrated tar (Engineering Standards No. 2)	58	per cent.
Pitch	28	,,
Trinidad Lake bitumen	7·5	,,
Resin	1·5	,,
Lime (dehydrated and in powder form)	4·0	,,
	100·0	

The proportions may have to be varied according to the consistency of tar and pitch that is used.

The Mixing Mill in which the aggregate and bituminous agent is mixed together is a mill having twin revolving horizontal shafts on which are placed fixed blades which reach to within 1 inch of the bottom of the mixer. The shafts run in opposite directions, and thus is ensured a thorough coating of the aggregate.

The bituminous composition must be in sufficient quantity to thoroughly coat each particle; the mixing should be complete in 1½ minutes As soon as the mass is properly coated, the bottom of the mixer is opened and the material dropped into the vehicle waiting below.

If bitumen is to be used as the binding agent it must be suitably fluxed with oil to bring it to a similar consistency, *i.e.* a penetration of 120 at 60° F., the weight to be 100 grms. and the time 1 second.

The mass when laid and rolled on the road should form a dense and compact concrete; the surface will present a number of small crevices. These crevices will act as a key for the surface coat which is to be laid on it subsequently.

For the spreading of the material prior to it being rolled, the men engaged on the work must be provided with rakes and shovels which are to be kept hot in order to facilitate the spreading and permit the work being expeditiously carried out.

Wearing-Surface Coat.—The asphaltic composition which is to form the wearing surface is to be composed of suitably graded minerals and bitumen.

The approximate analysis is as follows :—

Bitumen		12	per cent.	
Passing	200 mesh	10 to 17	,,	35 to 40 per cent.
,,	100 ,,	10 ,, 15	,,	
,,	80 ,,	10 ,, 15	,,	
,,	50 ,,	25 ,, 50	,,	35 ,, 45 ,,
,,	40 ,,	5 ,, 10	,,	
,,	30 ,,	5 ,, 10	,,	
,,	20 ,,	5 ,, 10	,,	15 ,, 25 ,,
,,	10 ,,	5 ,, 10	,,	
retained on	10 ,,	1 ,, 5	,,	

The actual grading must be submitted to and approved by the engineer, who may order or permit a modification.

Each of the particles must be clean, sharp, and free.

Of the 200-mesh material a large proportion, *i.e.* 8 per cent., shall not, when placed in a flask about 6 inches high which has been filled with distilled water at a temperature of 77° F., after being vigorously agitated, subside to the bottom of the flask within fifteen seconds after the agitation has ceased.

The Bitumen to be employed shall be free from moisture or decomposed organic matter, homogeneous, and present an even, regular glossy face when placed in a sample tin and allowed to cool.

The penetration of a No. 2 cambric needle, weighted with 100 grms. at 1 second, should be 60 at 77° F., as indicated on a Bower penetrometer, not less than 3 at 32° F., and not more than 200 at 120° F.

The loss on heating for seven hours at 325° F. shall not be greater than 4 per cent.

The loss on heating for seven hours at 400° F. shall not be greater than 8 per cent.

It shall be soluble in 88° naphtha to the extent of not less than 60 per cent. or more than 75 per cent. of total bitumen soluble in carbon bisulphide. It shall not be more than $1\frac{1}{2}$ per cent. less soluble in carbon tetrachloride than in carbon bisulphide, both tests being made at air temperatures.

The amount of fixed carbon shall not exceed 15 per cent., and the amount of paraffin scale not to exceed 3 per cent.

The film of bitumen on each surface of the particles employed in the composition shall not be less than ·00065 inch thick, calculated according to the table on page 190 of this book.

When the mixing of the aggregate and bitumen has been made and a batch deposited in the vehicle, a sample shall be taken from the bulk and a pat-paper test made; the stain left on glazed paper shall approximate closely to that shown on Plate II., page 202, of this book.

The materials, mixing, and the tests shall be made by the engineer or by the contractor at his expense, and the whole of the manufacture shall be open to the inspection of the engineer at all times during the progress of the work.

The heating of the aggregate shall be brought to a temperature of about 400° F., and shall be mixed in the mixer (already described—the blades in this case will reach within $\frac{1}{4}$ inch of the bottom of the mixer) at a not lower temperature than 320° F., and to such an extent that each particle is properly and thoroughly coated and the composition issuing from it homogeneous.

The wearing-surface coat shall be laid so as to give a rolled thickness of 1½ inches. The composition must be delivered at the road in vehicles suitably insulated so that the temperature of the material when deposited is not lower than 250° F It must then be properly spread and pushed into position by hot rakes in such a manner as to facilitate a homogeneous mass being secured when it is rolled. The surface is to be rolled while still in a moderately hot state with a 6-ton tandem roller,[1] the roller wheels to give not more than 250 lbs. to the inch run of tread. Longitudinal and cross rolling to be done until the surface is even and regular

If the surface shows signs of fine cracks, it will indicate that the understructure is unsatisfactory, and this area must be taken out and replaced with such material as will give the necessary results. Any areas which show the composition to be non-homogeneous must be filled up with hot material and ironed hot to an even face.

Samples of the pavement when laid shall from time to time be taken from the road after the wearing surface has been laid and tested by analysis and grading. The results must conform to the specified analysis in such a manner as will be approved by the engineer.

BRITISH STANDARD NOMENCLATURE OF TARS, PITCHES, BITUMENS, AND ASPHALTS WHEN USED FOR ROAD PURPOSES.[2]

Introductory Remarks.

The materials now used by road engineers for binding together the stones and other mineral aggregate used to form road crusts and road surfaces may be conveniently divided into three groups. These are :—

1. The tars and pitches obtained by the destructive distillation of coal or similar substances.
2. The bitumens and asphalts which are found in nature, or are obtained artificially from asphaltic oils.
3. Chemical binders, including the Portland and natural cements, which owe their cementing value as road binders to chemical action, and which are not dealt with in the present report.

[1] There is a divergence of opinion on the weight of roller; the ordinary 10-ton roller has been used on the wearing-surface mixture and it has given excellent results from the point of view of "finish" to the surface, but whether it will last as long is doubtful, because the severer the compression the sooner will actual wear begin. On the other hand, it may assist in giving a less wavy surface.

[2] Reproduced by permission of the British Engineering Standards Association (formerly the Engineering Standards Committee) from their Report No 76, 1916.

Hitherto the term "bituminous material" has been loosely applied to tar products as well as to bitumens and asphalts, but the Committee have from the first considered that it was desirable from the road engineers' point of view to maintain a sharp line of demarcation between the two groups. The views put forward in correspondence from America and by American engineers of standing and experience have been carefully considered, but the Committee still adhere strongly to the view that the description "bituminous" should be applied only to the second group

In this country the first group of road binders, the coal tars and pitches, has been in use for many years, and as the Road Board in 1911 issued Specifications for the tars, tar oils, and pitches, which they recommended for road purposes, these materials have already to some extent been defined by those Specifications. The Road Board early in 1914 issued a second edition of these Specifications. Only two classes of tar and one class of pitch are dealt with, and as these Specifications are of such recent date, the Committee recommend that they be adopted provisionally as the British Standard Specifications for tars and pitches used for road work.

The Committee find that the choice of names for the second group of road binders is a matter of some difficulty. The difficulty is increased by the fact that whilst it is desirable to obtain the concurrence of the American engineers to the nomenclature and definitions which the Committee now propose, the adoption of the American nomenclature for the various materials composing this group would be liable to lead to confusion and misunderstanding in this country.

The Committee have been very anxious to secure uniformity with American practice, and have carefully and fully considered the definitions adopted by the American Society for Testing Materials, and by the Committee of the American Society of Civil Engineers, put forward by the American corresponding members, but it is felt that the definitions now decided on are preferable from the road engineers' point of view, as they are based on those characteristics of the materials which can be most readily verified when employed for road making.

In accordance with this view, the Committee consider that it is desirable to make a sharp distinction between coal tar and paraffin-oil derivatives on the one side, and native bituminous substances and asphaltic oil residues on the other, and they are therefore unable to accept the American definition of bitumen which would include the coal tars.

Definitions.

First Group.

TAR PRODUCTS (PRINCIPALLY COAL TAR AND PITCH).

Definition of Tar.—Tar is the matter (freed from water) condensed from the volatile products of the destructive distillation of hydrocarbon matter, whether this be contained in coal, wood, peat, oil, etc

Prefix denoting Source of Origin or Method of Production. A prefix such as "coal," "wood," "peat," "gasworks," "blast furnace," "coke oven," etc., must be added to the word "tar" to indicate the source of origin or method of production.

Definition of Pitch.—Pitch is the solid or semi-solid residue from the partial evaporation of tar.

Second Group.

BITUMENS AND ASPHALTS.

Definition of Bitumen.—Bitumen is a generic term for a group of hydrocarbon products soluble in carbon disulphide, which either occur in nature or are obtained by the evaporation of asphaltic oils. The term shall not include residues from paraffin oils or coal-tar products

NOTE.—Commercial materials may be described as bitumen if they contain not less than 98 per cent of pure bitumen as defined above.

Definition of Native Bitumen.—Native bitumen is bitumen found in nature, carrying in suspension a variable proportion of mineral matter.

The term "native bitumen" shall not be applied to the residuals from the distillation of asphaltic oils.

Definition of Asphalt.—Asphalt is a road material consisting of a mixture of bitumen and finely graded mineral matter. The mineral matter may range from an impalpable powder up to material of such a size as will pass through a sieve having square holes of ¼ inch side.

Definition of Native or Rock Asphalt.—Native or rock asphalt is a rock which has been impregnated by nature with bitumen.

Prefixes denoting Source of Origin.—The Committee recommend that for convenience of identification prefixes denoting geographically the source of origin should be attached to each of the four terms defined above.

NOTE.—*The Committee desire to call attention to the fact that these Specifications are intended to include the technical provisions necessary for the supply of the material herein referred to, but do not purport to include all the necessary provisions of a contract.*

BRITISH STANDARD SPECIFICATIONS FOR TAR FOR ROAD PURPOSES.

(*Based upon the Road Board Specifications Nos.* 4 *and* 5, *and published with the approval of the Road Board.*)

Standard tar for road purposes in the United Kingdom shall be specified as under:

BRITISH STANDARD SPECIFICATION FOR NO. 1 TAR.

General.—This tar is suitable for the surface tarring of roads.

As to the use of this tar for making tar macadam, see " Road Board General Directions for Surfacing with Tar Macadam."

Heating.—The tar should be heated to such a temperature that it will reach the road surface in a highly fluid condition. The necessary temperature to attain this end will vary with the mode of application of the tar. The tar should be heated in a heater or " boiler " specially designed to prevent frothing, which will otherwise inevitably occur if the tar contains even a small percentage of water. The desired temperature will generally be found in practice to be between 220° and 240° Fahrenheit, or 104° and 116° Centigrade in the heater or boiler.

Source of the Tar.—The tar shall be derived wholly from the carbonisation of coal, except that it may contain not more than 10 per cent. of its volume of the tar (or distillates or pitch therefrom) produced in the manufacture of carburetted water gas.

Specific Gravity.—The specific gravity of the tar at 15° Centigrade (59° Fahrenheit) shall be as nearly as possible 1·19, and in no case shall it be lower than 1·16 or higher than 1·22.

Freedom from Water and Ammonia.—The tar shall be commercially free from water, *i.e.* it shall not contain more than 1 per cent. by volume of water or ammoniacal liquor, which water or liquor (if present) shall not contain more ammonia, free or combined as carbonate or sulphide, than corresponds to 5 grains of ammonia per gallon (= 70 milligrammes per litre) of the tar.

The amount of water or liquor is to be determined by condensation from the products of distillation of the tar by cooling with a cold-water condenser. Any water so condensed, after measurement, should be separated from light oils which may have condensed with it, and the

amount of ammonia in it should be estimated by direct titration with standard acid. The amount of ammonia thus determined should be calculated in terms of grains of ammonia per gallon of tar.

Fractionation.—On distillation in a litre fractionating flask (a distillation flask without special fractionating column) one-half to two-thirds filled the tar shall yield the proportions by weight of distillates stated below, the temperatures of distillation being read on a thermometer of which the bulb is opposite the side tube of the flask:—

> Below 170° Centigrade or 338° Fahrenheit, not more than 1 per cent of distillate (light oils), exclusive of water.
>
> Between 170° and 270° Centigrade or 338° and 518° Fahrenheit, not less than 16 per cent. and not more than 26 per cent. of distillate (middle oils).
>
> Between 270° and 300° Centigrade or 518° and 572° Fahrenheit, not less than 3 per cent. and not more than 10 per cent. of distillate (heavy oils).

The total distillate between 170° and 300° Centigrade, or 338° and 572° Fahrenheit, shall be not less than 24 per cent. and not more than 34 per cent.; *i.e.* where the middle oils approach the maximum allowed, the heavy oils should approach the minimum allowed, and *vice versa*

Naphthalene.—The distillate between 170° and 270° Centigrade, or 338° and 518° Fahrenheit (middle oils), shall remain clear and free from solid matter (crystals of naphthalene, etc.) when maintained at a temperature of 30° Centigrade for half an hour.

This requirement may be waived in the case of tar supplied direct from gasworks, but the tar from which the naphthalene has been extracted is preferable to tar containing much naphthalene.

Phenols.—The distillate between 170° and 270° Centigrade, or 338° and 518° Fahrenheit (middle oils), shall not yield to caustic soda solution more crude tar acids (phenols) than is equivalent to 3 per cent. by volume of the tar.

The following is the standard method of estimating the crude tar acids:—

Warm the middle oils to about 30° C. in a measuring cylinder. Weigh a flask of about 150 c.c. capacity; pour 100 c.c. of the warm middle oils into it, and weigh again. The difference gives the weight of 100 c.c of the middle oils. Warm the oils in the flask to 40°–50° C.; add to them 30 c.c of solution of caustic soda, having a specific gravity of about 1·2, shake the mixture vigorously and keep it at 40°–50° C. for fifteen minutes. Then shake the mixture again vigorously for a minute, pour it into a stoppered-separating funnel, and allow it to rest therein

until the solution of caustic soda has separated from the oil. If separation does not take place rapidly and distinctly it may be facilita by adding 25 c c. of benzol to the mixture. The soda solution free fr oil is drawn off through the tap of the funnel into a 100-c.c. measur cylinder, and the oil is returned to the flask, and warmed and extrac with 20 c c of solution of caustic soda exactly as before. This se solution is also drawn off into the 100-c c. measuring cylinder, the c tents of which are made slightly acid by gradual addition, with ge stirring, of hydrochloric acid. The crude tar acids separate and co to the top on standing, and their volume is read off on the scale of measure. Since 100 c.c. of the middle oils was taken for the esti tion, the reading gives directly the percentage of crude tar acids in middle oils.

If n=volume of tar acids found, w=the weight in grammes of 100 c of the middle oils: x=the percentage (by weight) of middle oils in t tar, and s=the specific gravity of the tar, then the percentage by volu of crude tar acids in the tar is $\frac{n\ x\ s}{w}$.

If 100 c.c. of middle oils is not available for estimation, a smal measured volume may be taken, and the quantitites of soda solution u reduced in proportion. The necessary modification of the calculati of the result can be readily made.

Free Carbon.—The tar shall contain not less than 12 per cent. a not more than 21 per cent. by weight of free carbon. The free carb is to be determined by the weight of the residue after complete extra tion of all matter soluble in benzol or disulphide of carbon. The e traction is best carried out in a Soxhlet or similar apparatus by disulphi of carbon followed by benzol.

BRITISH STANDARD SPECIFICATION FOR No. 2 TAR.

General.—This tar is suitable for making tar macadam, and al may be used for surface tarring in very hot weather when the ro crust is exceptionally dry.

Heating.—For surface tarring the tar should be heated to such temperature that it will reach the road surface in a highly fluid co dition. The necessary temperature to attain this end will vary wi the mode of application of the tar. The desired temperature will generally found in practice to be between 260° and 280° Fahrenhe or 124° and 138° Centigrade in the heater or "boiler." The tar shou be heated in a heater or "boiler" specially designed to prevent frothin which will otherwise inevitably occur if the tar contains even a sma

percentage of water. For the preparation of tar macadam the tar will not generally need to be heated to so high a temperature as for surface tarring, but the necessary temperature should be determined largely by the sensible heat of the stone treated with the tar, and the mode of application or treatment.

Source of the Tar.—The tar shall be derived wholly from the carbonisation of coal, except that it may contain not more than 25 per cent. of its volume of the tar (or distillates or pitch therefrom) produced in the manufacture of carburetted water gas.

Specific Gravity.—The specific gravity of the tar at 15° Centigrade (59° Fahrenheit) shall be as nearly as possible 1·21, and in no case shall it be lower than 1·19 or higher than 1·24.

Fractionation.—On distillation in a litre fractionating flask (a distillation flask without special fractionating column) one-half to two-thirds filled, the tar should yield the proportions by weight of distillates stated below, the temperatures of distillation being read on a thermometer of which the bulb is opposite the side tube of the flask:—

Below 170° Centigrade or 338° Fahrenheit, not more than 1 per cent of distillate (light oils and water, if any)

Between 170° and 270° Centigrade or 338° and 518° Fahrenheit, not less than 12 per cent. and not more than 18 per cent. of distillate (middle oils).

Between 270° and 300° Centigrade or 518° and 572° Fahrenheit, not less than 6 per cent. and not more than 10 per cent. of distillate (heavy oils).

The total distillate between 170° and 300° Centigrade, or 338° and 572° Fahrenheit, shall not be less than 21 per cent. and not more than 26 per cent., *i.e.* where the middle oils approach the maximum allowed the heavy oils should approach the minimum allowed, and *vice versa.*

Naphthalene.—The distillate between 170° and 270° Centigrade, or 338° and 518° Fahrenheit (middle oils), shall remain clear and free from solid matter (crystals of naphthalene, etc.) when maintained at a temperature of 25° Centigrade for half an hour.

Phenols.—The distillate between 170° and 270° Centigrade, or 338° and 518° Fahrenheit (middle oils), shall not yield to caustic soda solution more crude tar acids (phenols) than is equivalent to 2 per cent. by volume of the tar.

The following is the standard method of estimating the crude tar acids:—

Warm the middle oils to about 30° C. in a measuring cylinder. Weigh a flask of about 150 c.c. capacity; pour 100 c.c. of the warm

middle oils into it and weigh again. The difference gives the weight of 100 c.c. of the middle oils. Warm the oils in the flask to 40°–50° C.; add to them 30 c.c. of solution of caustic soda, having a specific gravity of about 1·2, shake the mixture vigorously and keep it at 40°–50° C. for fifteen minutes. Then shake the mixture again vigorously for a minute, pour it into a stoppered separating funnel, and allow it to rest therein until the solution of caustic soda has separated from the oil. If the separation does not take place rapidly and distinctly, it may be facilitated by adding 25 c.c. of benzol to the mixture. The soda solution free from oil is drawn off through the tap of the funnel into a 100-c c. measuring cylinder, and the oil is returned to the flask, and warmed and extracted by 20 c.c. of solution of caustic soda exactly as before This soda solution is also drawn off into the 100-c.c. measuring cylinder, the contents of which are made slightly acid by gradual addition, with gentle stirring, of hydrochloric acid. The crude tar acids separate and come to the top on standing, and their volume is read off on the scale of the measure. Since 100 c.c. of the middle oils was taken for the estimation, the reading gives directly the percentage of crude tar acids in the middle oils.

If n=volume of tar acids found, w=the weight in grammes of 100 c.c. of the middle oils: x=the percentage (by weight) of middle oils in the tar, and s=the specific gravity of the tar, then the percentage by volume of crude tar acids in the tar is $\frac{n\,x\,s}{w}$.

If 100 c c. of middle oils is not available for the estimation, a smaller measured volume may be taken, and the quantities of soda solution used reduced in proportion. The necessary modification of the calculation of the result can be readily made.

Free Carbon.—The tar shall contain not less than 12 per cent. and not more than 22 per cent. by weight of free carbon. The free carbon is to be determined by the weight of the residue after complete extraction of all matter soluble in benzol or disulphide of carbon. The extraction is best carried out in a Soxhlet or similar apparatus by disulphide of carbon followed by benzol.

THE TESTING OF TAR.

The compliance of a sample of tar with the British Standard Specifications for No. 1 and No. 2 Tars can be ascertained only in a chemical laboratory. But in cases where it is desired to ascertain in a quick and simple manner whether consignments of tar differ fundamentally

from an approved sample, or whether they are of the No. 1 or of the No. 2 grade, the following simple tests may be of service :—

Specific Gravity.—The specific gravity may be ascertained quickly and with a sufficient degree of accuracy by means of a hydrometer, to the readings of which a correction for deviation of temperature from the standard temperature of 15° Centigrade or 59° Fahrenheit is applied A hydrometer for the range 1·16–1·24, which is wholly made in nickel silver and will stand a reasonable amount of rough usage, is convenient, and this may be obtained in conjunction with a temperature corrector consisting of a substantial thermometer graduated to show directly the addition which should be made to the hydrometer reading when the temperature of the tar is above 15° Centigrade or 59° Fahrenheit. If a portion of the tar is poured into a suitable vessel, stirred, and the metal hydrometer and temperature corrector inserted in it, the specific gravity of the tar at 15° Centigrade or 50° Fahrenheit is obtained in two or three minutes, even though the temperature of the tar at the time is considerably higher than 15° Centigrade or 59° Fahrenheit.

The specific gravity of a tar is not by itself a sufficient indication of the utility of the tar.

Viscosity.—A viscosimeter will show quickly whether a sample of tar is of the No. 1 or of the No. 2 grade, or whether a consignment differs fundamentally from an approved sample, but since viscosity of tar varies greatly with its temperature, it is necessary that readings of viscosity, in order to be comparable, should be made at the same temperature. The temperature of 25° Centigrade (77° Fahrenheit) is a convenient standard temperature for observations of the viscosity of tar, and it is necessary before using the viscosimeter that the tar should be exactly at this temperature and well stirred. In cases where serious disagreement is found between the viscosity of an approved sample and the viscosity of the tar as supplied, further examination of the latter should be made before it is used.

Water and Naphthalene.—If about a quart of the tar is poured into a vessel about 12 inches high, and the vessel is covered by a piece of ordinary glass and is left standing in a moderately warm room for twenty-four hours, flaky white crystals of naphthalene will be seen on the glass and the upper part of the walls of the vessel if there is a considerable amount of naphthalene in the tar. Globules of water also will be noticeable on the surface of the tar at the end of twenty-four hours if the tar contains a considerable

quantity of water. Since most tars contain some naphthalene and often a trace of water also, it is advisable when making this test to put alongside the portion of tar which is being tested a portion of the approved sample in a similar glass-covered vessel, and to compare the amount of naphthalene crystals deposited and of water separated from the two samples at the end of twenty-four hours.

BRITISH STANDARD SPECIFICATION FOR PITCH FOR ROAD PURPOSES.

(Based upon the Road Board Specification No. 6, and published with the approval of the Road Board.)

Standard pitch for road purposes in the United Kingdom shall be specified as under :—

BRITISH STANDARD SPECIFICATION FOR PITCH.

General.—This pitch is suitable for pitch-grouting. See "Road Board General Directions for Pitch-Grouting."

Consistency.—The pitch is obtained of the required consistency most conveniently by running it off from tar stills in which the distillation of the tar has been stopped at the point at which the residual pitch will give a penetration of 70 (or such other penetration as may be specified to suit climatic or local conditions) when tested at 25° Centigrade (77° Fahrenheit) on a penetrometer. Harder pitch may be softened or cut back, in the still or in a mixer at the tar works, to the extent necessary for it to give this penetration, by the addition of tar oil.

Where pitch of the required consistency is not thus directly procurable, it may be prepared by softening commercial soft pitch, by the addition of tar oil. "Commercial soft pitch" and "tar oil" are specified on pages 276 and 277. In preparing the softened pitch in this manner the tar oil is added to the pitch in the manner described under "Instructions for Melting the Pitch" in the "Road Board General Directions for Surfacing with Pitch-grouted Macadam," in such proportions that the resultant softened pitch will give a penetration of 70 (or such other penetration as may be specified to suit climatic or local conditions) when tested at 25° Centigrade (77° Fahrenheit) on a penetrometer, with a No. 2 needle weighted to 100 grammes for five seconds.

PREPARED PITCH FROM TAR DISTILLERIES.

General Characteristics.—Pitch which has been procured of the required consistency directly from a tar distillery needs only to be

thoroughly melted in the pitch heaters or boilers, but, as a precaution against burning, 1 to 2 per cent of tar oil may advantageously be put into the boilers with the pitch.

Pitch which has been procured of the required consistency directly from a tar distillery shall not yield more than 4 per cent. of distillate below 270° Centigrade, or 518° Fahrenheit, on distillation as described below, and shall contain not less than 16 per cent. and not more than 28 per cent. of "free carbon," as defined below.

COMMERCIAL SOFT PITCH.

Source of Pitch.—The pitch shall be derived wholly from tar produced in the carbonisation of coal, except that it may contain not more than 25 per cent. of pitch derived from tar produced in the manufacture of carburetted water gas.

Fractionation.—On distillation in a litre fractionating flask (a distillation flask without special fractionating column) one-half to two-thirds filled, the pitch shall yield the proportions by weight of distillates stated below, the temperatures of distillation being read on a thermometer of which the bulb is opposite the side tube of the flask:—

Below 270° Centigrade or 518° Fahrenheit, not more than 1 per cent. of distillate

Between 270° and 315° Centigrade or 518° and 599° Fahrenheit, not less than 2 per cent. and not more than 5 per cent. of distillate.

Free Carbon.—The pitch shall contain not less than 18 per cent. and not more than 31 per cent by weight of free carbon. The free carbon is to be determined by the weight of the residue after complete extraction of all matter soluble in benzol or disulphide of carbon. The extraction is best carried out in a Soxhlet or similar apparatus by disulphide of carbon followed by benzol.

TAR OIL.

Source of Tar Oil.—The tar oil to be used is preferably a filtered green or anthracene oil, and shall be derived wholly from tar produced in the carbonisation of coal or from such tar mixed with not more than 25 per cent of its volume of tar produced in the manufacture of carburetted water gas.

Specific Gravity.—The specific gravity of the tar oil at 20° Centigrade (68° Fahrenheit) shall lie between 1·065 and 1·085.

Freedom from Naphthalene and Anthracene.—The tar oil after standing for half an hour at 20° Centigrade (68° Fahrenheit) shall remain clear and free from solid matter (naphthalene, anthracene, etc.).

Fractionation.—The tar oil shall be commercially free from light oils and water. On distillation in a litre fractionating flask (a distillation flask without special fractionating column) one-half to two-thirds filled, the tar oil shall yield the proportions by weight of distillates stated below, the temperatures of distillation being read on a thermometer of which the bulb is opposite the side tube of the flask:—

Below 170° Centigrade or 338° Fahrenheit, not more than 1 per cent. of distillate (light oils and water, if any).

Below 270° Centigrade or 518° Fahrenheit, not more than 30 per cent. of distillate (middle oils, and light oils and water, if any).

Below 330° Centigrade or 626° Fahrenheit, not less than 95 per cent. of distillate (heavy oils, middle oils, and light oils and water, if any).

INDEX.

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